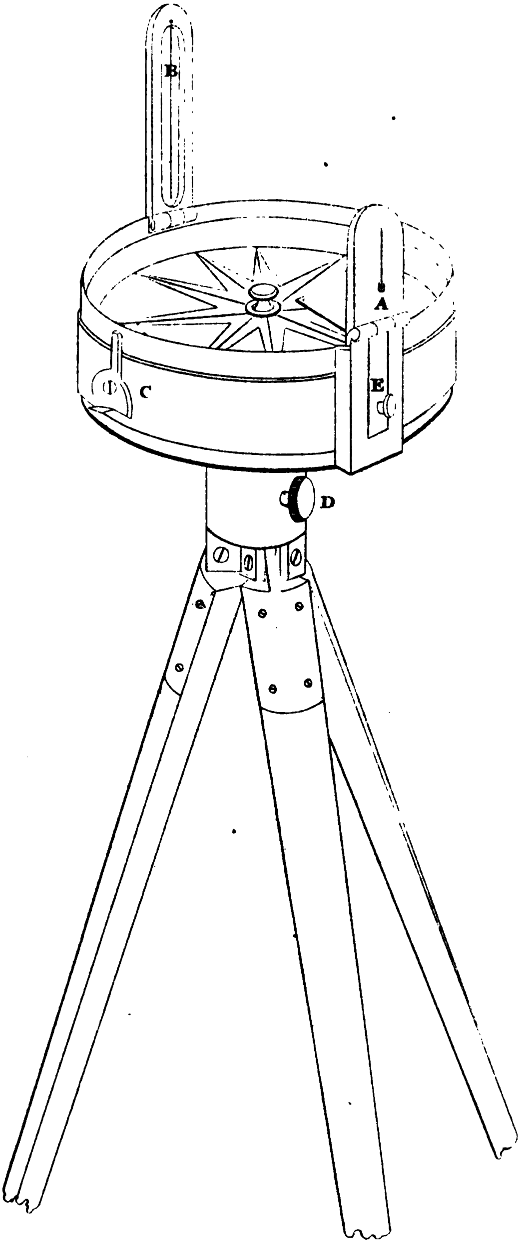

THE SURVEYING COMPASS.

A TREATISE

ON

MILITARY SURVEYING;

INCLUDING

SKETCHING IN THE FIELD,

PLAN-DRAWING, LEVELLING,

MILITARY RECONNOISSANCE,

ETC. ETC. ETC.

ALSO A PARTICULAR DESCRIPTION OF THE

SURVEYING INSTRUMENTS

COMMONLY EMPLOYED BY MILITARY MEN, WITH INSTRUCTIONS FOR USING AND ADJUSTING THEM.

BY LIEUT.-COLONEL BASIL JACKSON,

LATE OF THE ROYAL STAFF CORPS. PROFESSOR OF MILITARY SURVEYING AT THE HON. EAST INDIA COMPANY'S MILITARY COLLEGE, ADDISCOMBE.

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TO

MAJOR-GENERAL FREETH, K.H.,

QUARTERMASTER-GENERAL OF THE FORCES.

MY DEAR GENERAL,

AN acquaintance with most of the subjects treated in this work being necessary to an Officer of the Quartermaster-General's Staff, I beg to inscribe an improved edition to you, as the head of that important Department. Moreover, your former service in the Royal Staff Corps, throughout the Peninsular war, well qualifies you to pronounce upon its merits and utility.

I am,

MY DEAR GENERAL,

Your obliged

and faithful servant,

BASIL JACKSON.

CROYDON, 1853.

CONTENTS.

ON LEVELLING.

MILITARY RECONNOISSANCE.

APPENDIX.

PLATES.

PREFACE.

HAVING gone through the prescribed course of education at the Royal Military College, served more than twenty years in the Royal Staff Corps,* and been, during a long period, Professor of Military Surveying at Addiscombe, I venture to recommend the principles and practice of Surveying, Sketching, &c., &c., that I have found most convenient and useful.

The design of the following work is to pioneer the way, and enable young officers and students

* A war corps, organized and armed as a body of infantry, but trained to the duties of Field-engineering. The officers were mounted, and expected to perform the services of the Quartermaster-General's Department—the Field-Officers ranking as Assistants, and the Captains and Subalterns as Deputy-Assistants; receiving, when in the field, forage and other allowances according to their staff-rank. The qualification for an officer was a military education, and four-fifths of the soldiers were mechanics. This corps was not broken up until many years after the termination of the late war, its services having been made available in the colonies.

for the military profession to acquire a competent knowledge of the readiest methods of making maps and plans, taking topographical sketches, &c., &c., unaided by an instructor: with this object, the plainest rules and examples are given, in order that no part of the Treatise should be found too difficult for a beginner of ordinary diligence and ability to understand and follow.

My collection of memoranda on Military Surveying not having been originally designed as a class-book, but rather to smooth the way for young officers, and induce them to cultivate an acquirement not only useful to the service, but often highly advantageous to themselves, the arrangement of the subjects is not according to the method of instruction that I would recommend teachers to pursue. When the work was adopted by two of our military colleges, it became a question whether a material alteration ought not to be made; but, considering that no course which I could lay down would be implicitly followed by any instructor, and with the satisfaction of believing the former arrangement to have been useful, I have forborne to make any very important changes in the later

editions. The order of instruction that I would recommend in military colleges and schools is as follows:—

1. Surveying with the Land-Chain, and Plotting the Survey.
2. Traversing with Prismatic Compass and Chain.
3. Trigonometrical Surveying and Traversing with a Theodolite.
4. Military Sketching with Pocket-Sextant and Prismatic Compass, using the marching step of 30 inches for measurements.
5. Military Sketching without Instruments.
6. Levelling in all its branches.

It is almost unnecessary to say that I stand indebted to many sources for much of the information this volume contains; but whenever anything has been borrowed from, or communicated by, others, I have always been careful to make due acknowledgment.

Finally, no pains have been spared to render this new edition as complete as lay in my power; and I now send it forth with the hope that it will prove useful to the Army at large.

MILITARY SURVEYING,

&c.

Military Surveying may be defined as the art of describing the face of country with reference to its capacity for warlike operations.

A military plan need not possess the accuracy of a regular and careful survey, but should be a faithful representation of the country it professes to pourtray, so as to convey a correct notion of the character and nature of its surface. It should abound in details, and be extremely minute and particular respecting mountains and their passes; points at which a river or morass may be crossed; localities offering military positions; nature of forests, &c. &c.

It may here be observed, that a good plan conveys to the mind a more perfect image than can be obtained by looking at the ground itself. A well-executed plan enables us to examine and compare the great geographical features of a country: we trace on it the directions of lines of coast,

of mountains, rivers, and roads. Distance is of no consequence; we see territory, twenty, fifty, a hundred miles off, and can estimate the comparative heights of mountains without having to bear in mind that the angle subtended by a hill varies with its distance from the eye, or that such an art as perspective exists. Nay more; it may be asserted that a really good plan is fully equal, if not superior, for military purposes, to the best model.

No military operation can be safely undertaken, or at least carried on advantageously, without a knowledge of the country in which it is to be executed. For a General to obtain this knowledge by a personal examination, amid the many calls upon his time and attention occasioned by his various and important duties, is manifestly impossible; hence the necessity of having attached to an army, officers qualified to furnish plans, sketches, and reports, and perform all duties connected with what is termed Military Reconnaissance.

A report should invariably accompany a plan, explanatory of all that the latter cannot show; so that from a perusal and examination of them conjointly, all the knowledge which they are intended to convey may be surely and speedily obtained.

Moreover, the utility of military plans is not confined to the period of actual operations, but is felt afterwards. Without them what would be the science of war? The profound combinations of the General, as well as the

graphic descriptions of the historian, would indeed avail us little, if the narrations of the latter were not illustrated by plans.

Further, the service requires not merely that plans should be executed, but also that the General and others, for whose information they may be prepared, should *understand* them. Hence, every officer—for all hope to rise in rank—ought to be at least sufficiently acquainted with Military Surveying to read its language as used in a plan. Certain details, as roads, rivers, houses, woods, &c., are, at a glance, comprehended by every one; but to distinguish the character and features of hills, mark their connexion, judge of their comparative height, steepness of slope, and other points relative to *ground*, and which are the most important considerations in a purely military plan, requires a real knowledge of the art; and it may be added, that few officers who have not had the advantage of a military education can ever understand *ground* as represented in a plan.

ON MILITARY SKETCHING WITH THE PRISMATIC COMPASS.

SECTION I.

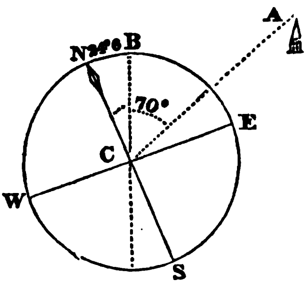
PRISMATIC COMPASS — TAKING BEARINGS — INSTRUMENTS AND IMPLEMENTS REQUIRED.

The most convenient instrument for taking the bearings of objects in military sketches is the prismatic compass. With this instrument, and pacing for distances, a survey of an extensive tract may be made with sufficient accuracy for military purposes. The survey may be either entered in a field-book, and the details sketched after the general outlines have been plotted, or the work may be plotted in the field, so as to bring home the survey complete.

The prismatic surveying compass, when mounted on a stand, and having the card divided to 20′, that is, each degree into three parts, enables the observer to obtain a bearing to within three or four minutes of a degree, by estimation. When held in the hand, a bearing may be depended on to about fifteen minutes, provided the wind is not so violent as to shake the hand of the observer. It is usual to watch the vibration of the divisions on each side of the vertical hair, and take the mean. I have found it most convenient when the card is divided into twice 180 degrees, instead of having it numbered from 0 to 360

degrees. The stand is better without levelling screws; they are troublesome, and, I may say, almost useless; for the card is easily made level enough to play freely, by shifting the legs of the stand: these should be between five and six feet long, for the convenience of the observer, and that the instrument may be above the height of brushwood, &c., which often impedes the view.

In surveying with the compass, the bearings of objects are taken from the *magnetic meridian*. Let N S represent the magnetic needle or meridian, W the west, and E the east; and suppose the sights of the compass are directed to the spire A; then if the angle N C A be 70°, for example, the spire is said to bear 70° north-east, or 70° from the magnetic north towards the east.



The *variation* of the needle is its deviation from the true north. In this figure, the angle N C B represents the variation, B C being considered as the true meridian. The variation is always changing, and is now something less than 24° west, at London.

Having made himself master of the instrument, so as to be able to take bearings, I recommend the student to attempt the sketch of a road; the mode of doing which I shall endeavour to render very easy to him. He will require to be provided with a sketching case, about ten or eleven inches square, an ivory rectangular protractor, such as every case of mathematical instruments is furnished with, and a black-lead pencil. His paper, asses-skin, (or what is preferable to either, a piece of paste-board,) fits into the sketching case, and must be ruled all over with very fine lines, exactly *parallel* to each other, and at

unequal distances, varying from a quarter to three-eighths of an inch apart.* The purpose to be answered by ruling the lines at unequal distances, we shall presently see. The protractor is six inches long, and an inch and three-quarters wide, having *across it* a number of very fine lines at right angles with its length, and at *equal* distances from each other,† constituting a scale of equal parts. For instance: if the distance between two red lines be taken as 100 yards, and the smallest divisions as 10, then the scale is that of four inches to a mile—seventeen large and six small divisions measuring exactly four inches. Hence, if a scale of eight inches to a mile be required, the distance between two red lines is 50 yards, and the small divisions become 5 yards each; and if a scale of two inches to a mile be required, the distance between the red lines becomes 200 yards, and the small divisions 20. But we may call the divisions on the scale 10, 20, 30, or any number we please, of yards, feet, links, or paces.

* *Sketching blocks* have lately been used for sketching and plotting in the field, and found very convenient. Each sheet of paper composing the block has parallel lines printed on it from a steel plate, which not only ensures the accuracy of their parallelism, but gives the lines very fine, which is a desideratum. A useful size for a *block* is twelve by ten inches, and it fits into a patent leather case, which may be slung over the shoulder or attached to a saddle. They are made by Messrs. Reeves, 113, Cheapside.

† It should be mentioned that these lines will not be found upon all ivory protractors; but those supplied by Messrs. Troughton and Simms, 138, Fleet Street, and Messrs. Elliot, 56, Strand, generally contain them.

SECTION II.

METHOD OF SKETCHING A ROAD BY MEANS OF THE COMPASS, AND PROTRACTING IN THE FIELD.

The compass is set up at the point from which we purpose to start, as A (plate II., fig. 1): and care being taken that the card be level, so as to play freely, a mark is placed at B, where the road turns to the right: the sights of the instrument are then directed to the mark at B, and we find, when the card has settled, that the vertical hair cuts the 29th degree; the bearing of B is therefore 29° north-east—the mark at B lying towards the east point from the magnetic north.—I would observe, that in ordinary road sketching, it is not usual to set up any marks: some object will present itself, which must be kept strictly in line when pacing the distance; thus, much time is saved.

Next, to protract, or lay down the bearing of B upon our paper, which has upon it the parallel lines at *unequal* distances, to be considered as *east* and *west*, and therefore not meridian lines, which are north and south.

The protractor has across it, as we have already noticed, a number of lines. Now, fix on any convenient part of the paper, make a dot, and surround it with a small circle, thus ⊙, which denotes a station. Place the centre of the protractor at this point, and endeavour to make any one of the lines which are drawn across it, to coincide with one of those upon the paper, being careful to keep its centre very exactly on the point. This being effected, the protractor

PLATE 2.

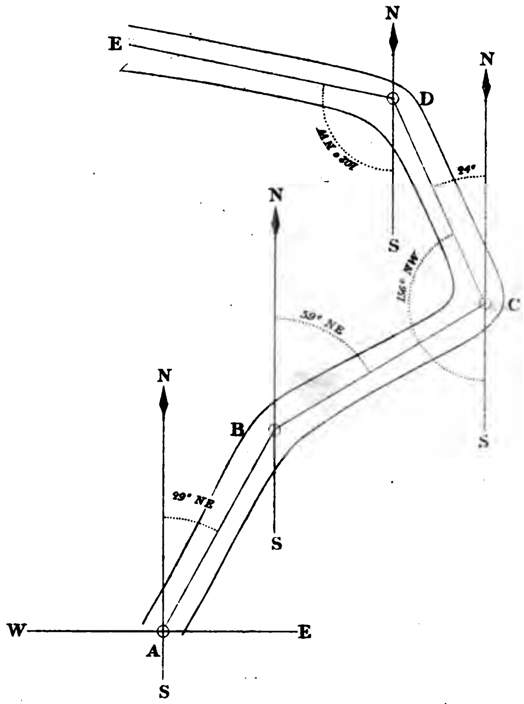
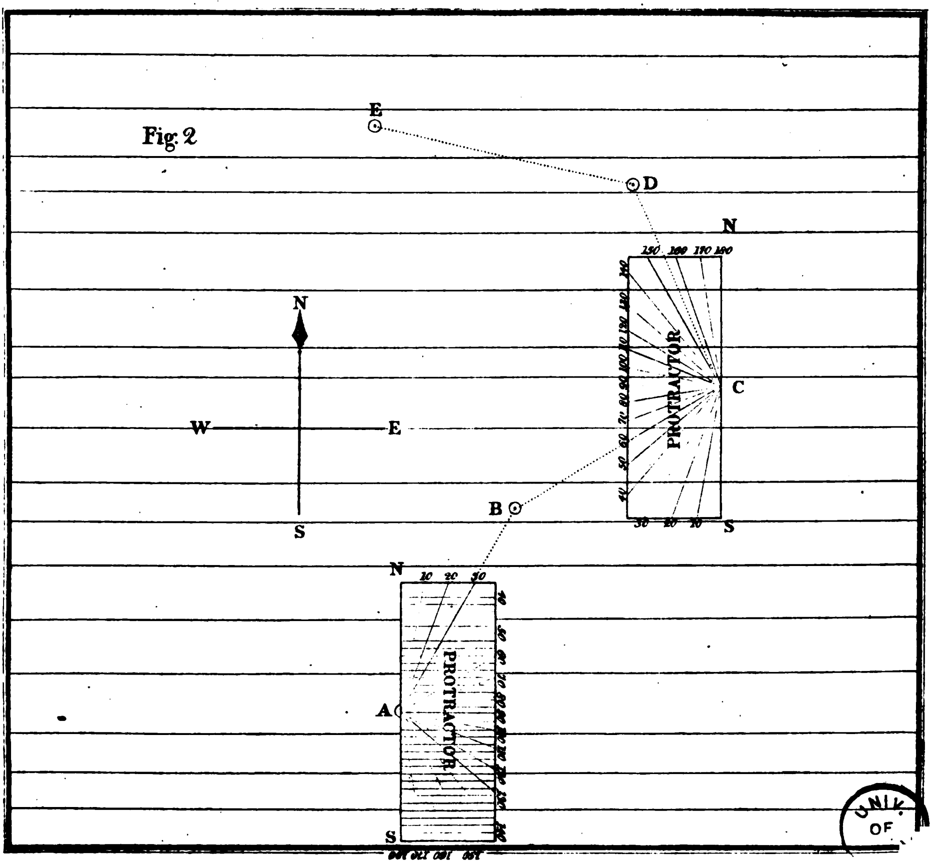


Fig. 1

Fig. 2



is adjusted, that is, lengthwise it will lie north and south, while its ends will, of course, be east and west. Make a small mark on the paper at the 29th division or degree, when the protractor may be removed. A line is then drawn from A, through that mark, which line will bear 29° N.E. You now measure the distance from A to B, which is effected by pacing, using the regular marching step of 30 inches. To lay off the distance measured: upon the line on your sketch, apply the edge of the protractor, which has a scale marked on it, or use a slip of paper upon which a scale of any size you please has been prepared, and mark off the distance. Finally, trace lines, as shown in the figure, to represent the sides of the road, and the first station is completed.

A mark is next placed at C, and its bearing taken from B, namely, 59° N.E.

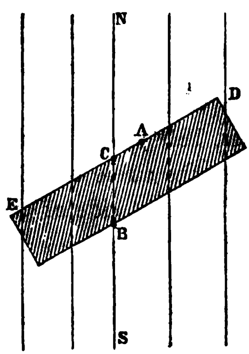
When we come to take the bearing of D from C, we find the sights of the instrument turned to the left of the magnetic north, while the vertical hair cuts the card at the 156th degree. Now, in the common mode of reading a bearing, we should say that D bore 24° N.W.; but our compass card reads, from north round to south, by the east, 180°; and then, from south to north, 180°, to complete the circle of 360°. Consequently, all bearings lying on the *west* side of the meridian are read off from south towards the north; and therefore in the present instance the bearing of D is 156° N.W.: that is, 156° from the south pole of the needle, round towards the north pole; and as this falls between the W. and N., it is styled north-west.

The expression of bearings may, however, be simplified, if we distinguish them only as *east* and *west;* we shall therefore, cease to designate them as being so many degrees north-east, south-west, &c., and *term all bearings taken*

from the north pole of the needle, up to 180°, *as* east; *while such as are measured from its south pole will be* west.

Fig. 2, plate II., represents the paper as prepared with parallel lines. The protractor is adjusted to station A, for laying down a bearing from north to east, and on to south. At ⊙ C, it is likewise adjusted, but reversed in its position, for the purpose of laying off the bearing of D, which, from what has just been observed, must necessarily be reckoned from south, round towards north, passing by west, the situation of which is indicated by 90° on the protractor, the west point being at right angles, or 90° from south.

When a protractor is not furnished with cross lines for its adjustment, by the east and west lines drawn on the paper, these may be considered as meridians (north and south); by means of which, bearings are laid down in the following manner:—Suppose that we want to protract a bearing of 60° E. from a point A. Place the centre, C, of the protractor on any meridian, N S, and turn it as on a pivot, until the 60th degree, reckoning from E, coincides with the same meridian at B. The protractor is then moved up or down, being careful to preserve its position on the meridian, until the upper edge touches the point A, when a line drawn from C through A will make the angle N C D = 60° = E C B.



It may be as well to mention here, that when surveying a road, or river, &c., with the compass, bearings need only be taken at every *second* station; as will be seen when Section IV. is understood.

The student will do well to make himself master of the

two first sections, before he proceeds further: with a little attention, I can assure him that the subject, thus far, will occasion him no embarrassment whatever. It is, perhaps, superfluous for me to mention that I consider it as entirely new to him, and have written accordingly.

SECTION III.

OF THE SIMPLEST METHOD OF SKETCHING A PORTION OF GROUND;* A MILITARY POSITION, FOR INSTANCE; WITH THE AID OF THE COMPASS.

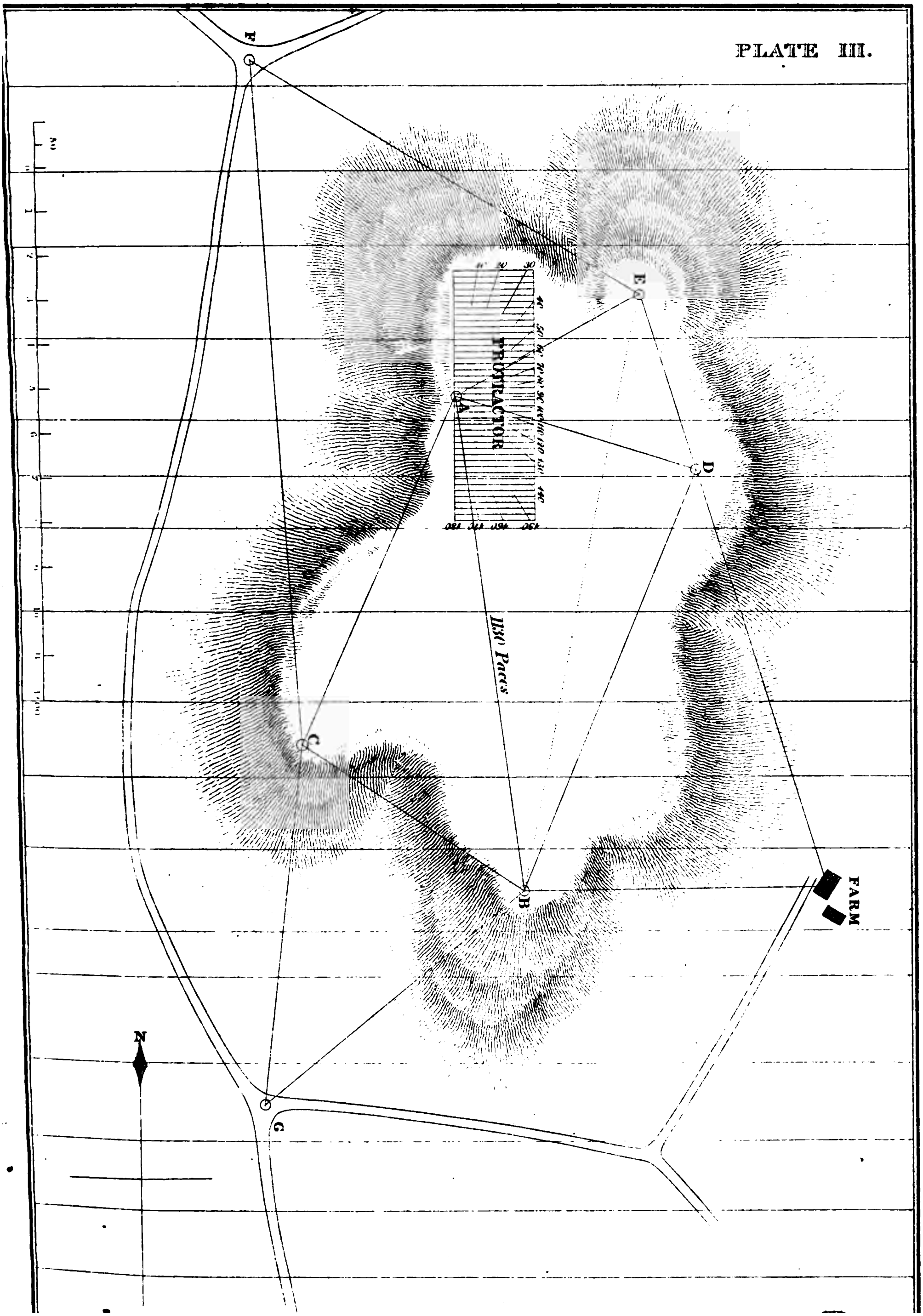
The paper must be ruled with parallel lines at unequal distances, as before.

Previously to commencing the sketch, it is best to go over the ground and examine it, so as to fix a plan of it on the mind. Then select a few prominent points for stations, from which bearings are to be taken to all conspicuous objects contained within the limits assigned to the sketch; such as houses, remarkable trees, a windmill, church steeple, &c. Next, select the longest and most level space on which to measure a base, which may be either on the summit of the ground you are to sketch, or along the bottom, as most convenient.

Plate III. represents a hill, partly surrounded by a road, of which our object is to take a military sketch with some degree of accuracy. On inspection, it is found that the direction A B is most favourable for the base line. E, D, and C, are situations eligible for stations. Now, the compass being placed at A, the bearing of E is taken, namely, 61° E. D is found to bear 106° 30′ E. B, 172° 20′ E. C, 24° 30′ W. Protract these several bearings, by marking a point, A, on the paper, in such a situation as will admit of the whole contemplated sketch being contained

* The term *ground* is generally to be understood as applied in contradistinction to a flat or level; so, whenever it is met with in the course of this work, hills or elevation will be meant.

PLATE III.



on the sheet, and adjusting the ivory protractor to the lines, as on the former occasion, which will then lie in the position that is shown in the figure. Measure the base A B. The mean of three times pacing it over gives, suppose, 1130 paces, of 30 inches each. Lay your scale along the line which indicates the bearing of B, and mark off the number of paces, which fixes the point B.

Again, plant the compass at B, and take the bearing of C, 124° W.; of A, 172° 20′ W.; of E, 11° E.; of D, 22° 30′ E. It will be remarked that the bearing of B from A, and that of A from B, give the same number of degrees and minutes: they form, in fact, alternate angles with their respective meridians, and present, when laid down, the same straight line; furnishing a proof that the bearing taken at A was correct.

The several bearings taken from B are now to be protracted, and the intersections with the lines drawn from A, fix the points C, E, and D.

The observer should now look around, and notice what objects are visible that it may be advantageous to fix, with a view to assist him in sketching, and filling in his work. For this purpose a bearing must be taken to the farm-house; also to the point G, where a road turns off. The farm bears 89° E., and G, 50° 30′ W. These two bearings are then to be protracted. Proceed with the compass to C, and take the bearing of G from thence, 6° W., which, on being laid down, cuts the bearing taken from B, and determines G. While at C, it is perceived that the point F, where a road branches off, must be fixed: a bearing is therefore taken to F, namely 175° 30′ W. The compass is then carried to D, and the position of the farm-house is decided by a bearing that cuts the one taken from B.

It is a maxim in surveying, that when fixing any points of importance, both acute and obtuse intersections are to

be avoided as much as possible. The nearer an intersection approaches to a right angle, the better: hence, in selecting primary stations, we should endeavour to have them so placed, that bearings which determine them shall intersect or cut each other as near at a right angle as circumstances will permit.

This observation applies particularly to the kind of rough surveying now under consideration; for it is manifest that some degree of error must attend every operation performed; for instance, the base line is measured by pacing—our compass only gives a bearing to within three or four minutes of the truth—the protractor is even more inaccurate, and, with every care, some error will attend its adjustment to the parallel lines. Now, if to all these unavoidable sources of error, we add such as will attend a very acute intersection, primary stations so determined, from which other points in the sketch are afterwards to be derived, must lead to great incorrectness.*

Referring to the sketch before us, E, standing on an elevated knoll, is higher than any other of the stations; and supposing the sketch extended beyond the limits here assigned to it, the point E, from its superior elevation, which enables us to look well around, ought to be carefully fixed. In this view, the lines A E and B E intersect too acutely for the degree of accuracy that is desirable, and ought therefore not to be solely trusted to; especially as station D furnishes an opportunity to correct the position of E. When at D, therefore, the bearing of E is to be taken for this object.

Lastly, the bearing of F is observed from E, and the line C F is intersected, thus fixing F where the roads meet.

* The student is not to be alarmed at this array of causes productive of error. In a sketch comprehending an area of a square mile, the most distant points will not be generally more than 30 or 40 paces out—a matter of little moment in a military sketch. But it was necessary to warn him on the subject.

The contours of the hill should be sketched in during the foregoing operations. Thus, after protracting the bearings taken at A, the declivities near that station are sketched in, having reference to the lines laid down. In the direction of C, for instance, we find that at 140 paces a descent begins, and at 145 paces further we regain the summit—still walking direct upon C. When C is fixed, a curve is swept round to meet what was sketched from A; and thus the business proceeds. But I shall not dwell longer on the *sketching* part in this place—proposing, in a subsequent section, to try and render the process intelligible to the student.

With regard to the road in our sketch, we find three points on it laid down, namely F, G, and the farm-house: the intermediate portions of it are either sketched in by the eye alone, or bearings may be taken along it, in the manner we have already seen (Section II.), to close from point to point—as from F, closing on G, and from G, on the farm.

If it were wished to carry the sketch over a greater extent of country, bearings to distant objects could be taken from points already fixed, as E, F, G, &c., and their several situations determined; and thus a net-work of triangles might be formed, similar to those of a trigonometrical survey. Indeed, our sketch is a minor description of trigonometrical survey. There is the base line A B. The primary stations, A, E, D, B, and C, with triangles formed by their bearings, laid down from each end of the base. Nothing can be more simple and easy than such an operation; and, notwithstanding the numerous sources of error above stated, a few square miles of country may be laid down in this manner with sufficient accuracy for every military purpose.

A scale should accompany each sketch, and a meridian line must be laid down.

SECTION IV.

OF FINDING YOUR PLACE IN A SURVEY OR SKETCH WHEN FILLING IN.

It is advisable in all kinds of surveying to have few original stations, and these as wide of each other as the nature of the country will allow. The primary points being accurately determined, such intermediate stations as become necessary when filling in are readily obtained in a very simple manner, by taking the bearings of two stations previously fixed; which has been called finding your station by *interpolation*, and is a truly useful little problem, that I shall now endeavour to explain. I may mention that there is another method of finding your place on a map or plan, by observing the two *angles* formed between *three* fixed points, for which see *Application of Trigonometry to measuring heights and distances.*

With respect to the division of the compass card, it will be remembered that I recommend its being divided into twice 180 degrees, instead of carrying the numbers round from 0 to 360 degrees; the advantage of which will be again seen here.

Let the circle N E S W (plate IV., fig. 1) represent the compass, having a line, H L, passing through its centre: the circle being divided into twice 180°, that is, the semicircle N E S is numbered from 0 to 180°, beginning at N; and the other semicircle S W N is numbered in like manner from S. Now, according to this mode of dividing the compass card, the bearing of the object H from C is

PLATE IV.

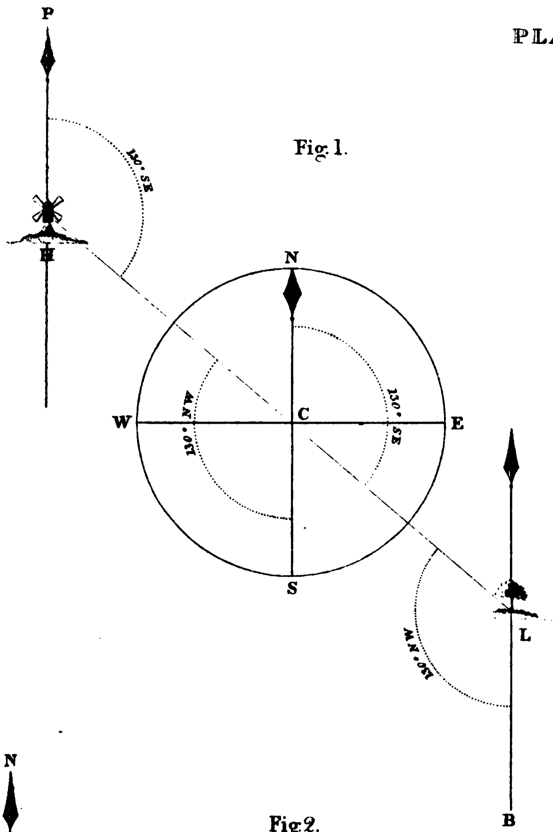


Fig. 1.

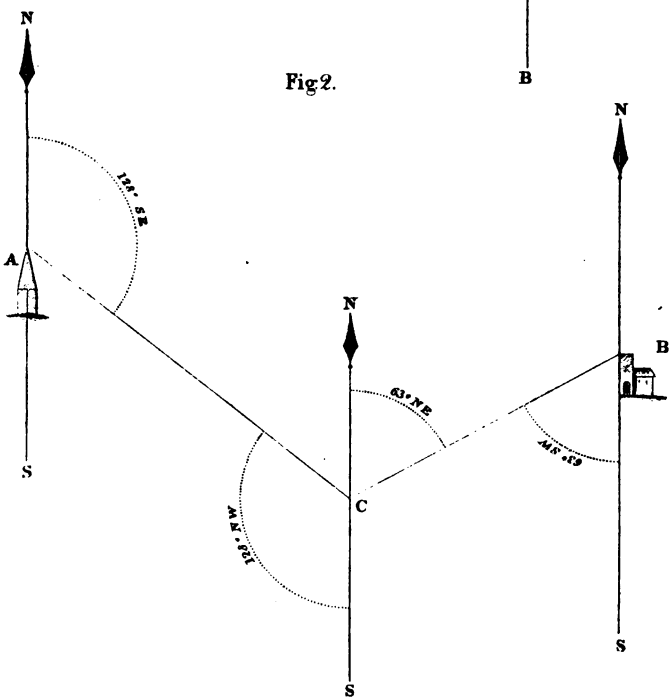


Fig. 2.

130° W., while that of the object L, from the same point C, is 130° E., H C L being a straight line—or it may be expressed thus, N S and beH Ling two right lines, cutting each other at C, the opposite angles are equal, namely, the angle H C S is equal to the angle N C L.

Again, let P H and B L be parallel to the meridian N S; these lines then become the meridians of the objects H and L respectively;* and P H being parallel to B L, the alternate angles P H C and B L C are equal. Hence if the bearing of the object H taken at L be 130°W., the bearing of L taken at H will be 130° E.

For the application of the above to our immediate purpose, namely, to find the place of a third station, by means of two stations already laid down on the paper:—

Let A and B (plate IV., fig. 2) be two stations, whose places are fixed, and we want to determine the point C. Take the bearing of A. 128° W.: having done which, we know, from the foregoing explanation, that C bears from A, 128° E. Adjust the protractor at A, by means of the east and west parallel lines, and lay off 128° E., the bearing of C; which point C must, we know, lie somewhere in the line thus obtained. Next, take the bearing of B, 63° E., and having adjusted the protractor at B, lay off 63° W., and where a line drawn from B (to represent this bearing) cuts the line or bearing drawn from A, is the required station C.

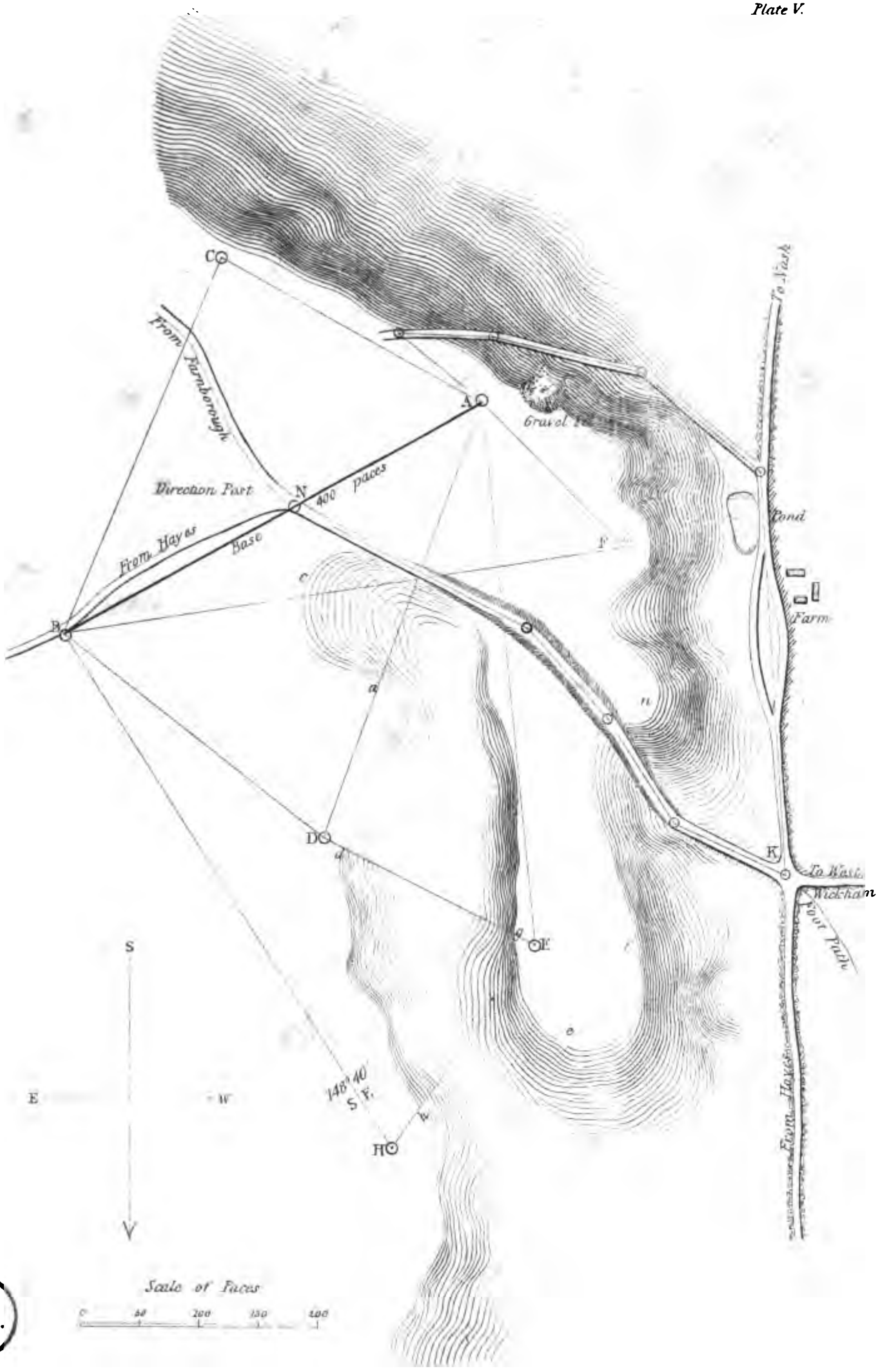
The above may be put into a short rule: thus—To find your station by observations taken to two points already known, protract *from those points* the *opposite* bearings to what you observe, and their intersection fixes the place sought. For example, if the bearing to a point be 20°E., protract from that point 20° W., &c.

* Strictly speaking, meridians are not parallels, but they may be considered as such for surveying purposes.

Observe that the nearer your two bearings meet at a right angle, the more correct will the station be determined: and also that when a third fixed point can be seen, a bearing to it will serve to corroborate your other observations; and a point so obtained, namely, by the exact meeting of three bearings, becomes as good as any other point.

The above is a very useful problem—indeed indispensable when sketching ground and filling in a survey.

Plate V.



C
From Farnborough
A
Gravel Pit
To Nash
Direction Post
N
400 paces
From Hayes
Base
Pond
Farm
B
D
K
To West Wickham
Foot Path
E
S
E
W
148° 40′
S E
H
From Hayes
Scale of Paces
0
50
100
150
200

SECTION V.

PROCESS OF A MILITARY SKETCH—SKETCHING FEATURES OF GROUND.

Let us now see how a sketch was actually performed upon the plan that I have attempted to describe in the foregoing pages.

Our ground (the western part of Hayes common, Kent) having been examined, it appeared that the line A B afforded the most advantageous base; as in most other directions furze bushes rendered it impossible to walk in a direct line. A B measured 400 paces of 30 inches. Bandrols were then planted at each end of the base, and also at such other points (C, D, E) as appeared most favourable for sketching the features of the ground.

The prismatic compass gave the bearings as under, from A, namely:

To F 136° 30′ W. (F being a remarkable tree.)
„ E 174° 40′ W.
„ D 19° 35′ E.
„ B 60° 35′ E. (direction of base.)
„ C 119° 25′ E.

We then went to B, whence the bearings were—

To C 19° 50′ W.
„ F 81° 20′ W.
„ D 128° 50′ W.

A point on our paper having been chosen for A, the ivory protractor was adjusted (page 8) and the several bearings laid off from it. Along the line representing the bearing of B, the length of the base, 400, was taken from

a convenient scale of equal parts, which determined the point B: the bearings observed from B being then protracted, the points F and D were fixed by intersections. We then proceeded to the bandrol D, and observed the bearing from thence of E, 117° 20′ W., and were thus enabled to fix that point by intersection with the line A E.

Sufficient points having been thus determined on our paper, we began to sketch the ground. Being at D, we commenced by observing that towards E it began to fall at 20 paces—this point was marked as *d*. We then returned to D, and walked direct upon A, until at 130 paces we came to the declivity at *a*: the curve from *d* to *a* was then marked on the paper, and a little shading performed. We then noticed how the ravine went with reference to C, and were enabled to sketch in as far as *c*. We then turned back, and passed D, going in the direction of H, until we came to a point that we saw would be useful to us—to determine which we set up our compass, and took a bearing to B of 148° 40′ E. Also one to E, of 36° 5′ W. To find our place then at H, we had only to adjust the protractor at B and at E, and protract the opposite bearings (see page 17); accordingly, we laid off from B, 148° 40′ W.; and from E, 36° 5′ E.: the intersection of these lines fixed H. Again for the sketching—looking towards E, the declivity began at about 30 paces from H, at *h*—the ground *h* to *d* was then sketched in.

E was our next point—the distance to *e* was found to be 75 paces, in continuation of the line A E. To fix *f*, we paced in a direction at right angles to the line, E A, 80 paces; and to *g*, being 15 paces, the curve *f e g*, was swept, and the ground shaded. We then noticed that the crest of the ravine continued for 100 paces nearly in the direction of A, after which it inclined somewhat to the left,

until at length the curve united with that portion of the sketch which was first put in. We then went to the point *n*, found our place by taking bearings to E and A, and sketched the ground there, uniting it with that at *f*.

Our next move was to the tree at F, round which we sketched the ground, uniting it with what had been already drawn in the direction of *n*. The sketching was then continued towards A.

It must be needless to say more about sketching the ground, so for as relates to this little plan—perhaps I have already been too minute.

The roads were thus put in:—the distance from B to N having been ascertained, the compass was set up at N, from whence bearings were taken towards K (Section II.), and from thence past the farm, until we ascended a road that brought us to the summit of the high ground near A, upon which station we closed with tolerable accuracy. It would have been desirable for us to have got sight of one or two of our primary stations during the course of our progress by the road; but almost immediately on leaving N, we entered a hollow way, which hid everything from our view, until we reached the bottom of the hill at K, from whence, could we have seen E and F, we should have taken bearings to those stations, in order to make sure of our place at K, and as a check on the work; but E was hidden by the brow of the hill, and F by trees, thickly strewed over the face of the ground in that part.

The student will perceive that, in the sketching above detailed, we could not possibly have been much out at any time; as the primary points, together with imaginary lines connecting them, enabled us to refer the contours of the ground to what had previously been laid down with some degree of certainty.

I shall now show the manner in which a military sketch

of the same ground was rapidly executed, without measuring a base line, or using other marks than some trees and bushes as they existed on the ground. The instrument used was a prismatic compass, held in the hand, and each individual was provided with a sketching block ruled with parallel lines, an ivory protractor, and a black lead pencil.

A tree, A (plate VI.), was selected as the point at which to commence operations: from whence we could distinguish a little knoll, I, a large tree, K, and the trees, C and B. No other objects visible from A seemed likely to be of service to us in sketching the ground, or putting in the roads. Bearings to those objects were then taken, viz., to I, 34° W.; to K, 52° W.; to C, 15° 30′ E.; and B, 125° W.; the distances of the trees, B and C, were then paced, and found to be 108 and 170 paces respectively, which determined their positions. When pacing between the trees at A and C, we noticed at what point the ground began to fall, and with the aid of the trees C and B, we were enabled to sketch the features of the ground in their vicinity; having done which, a bearing from C was taken to a small bush, on the summit of the hill at D, 161° 40′ W., and the distance CD, was found to be 150 paces. The ground about D was then sketched, and connected with that already done. The bearing of a bush, P, was next taken, and from thence a bearing to a distant object, of 57° E., enabled us to put in the ground as it appears in the sketch. Returning to D, the direction of a bush at E was ascertained, and its distance from D found to be 165 paces. A bearing then taken from E upon A, served to check the work thus far.

The point, F, was taken in line with the trees, A and B, 80 paces from the latter; the bearing of a tree, G, being then taken, was found to be 17° W. the ground was sketched towards G, and the distance determined by pacing.


S
E
W
From Keston
Gravel Pit
Direction Post
From Hayes
Pond
Farm
To Wickham
Foot Path
To Hayes
A
B
C
D
E
F
G
I
K
L
M
N
O
P
X
Scale of Paces of 30 inches

We then returned to A, and paced towards I, sketching in the head of the ravine near M, and making a mark on the road at that point: the distance between A and I, measured 495 paces. The point I having been thus determined, the bearings of the trees, K and N, were taken from thence; after which pacing upon N, the ground between M and that point was sketched. The tree B being visible from N, its bearing was observed as a check; and a bush, O, being found to bear 171° W., the length and breadth of the summit of the hill between N and O were measured as marked on the sketch.

It must be unnecessary to detail how the rest of the sketch was obtained; as, with a little attention, the student can readily make it out for himself.

To put in the roads was our next object. We found the point, M, by pacing from A upon I, as already noticed, and then took bearings down the road to the point, X, and from thence by the farm and pond, up the hill, past the gravel-pit and the knoll, I.

This process may do very well for a sketch of limited extent, such as is represented in plate VI.; but for larger sketches it must be manifest that by triangulation alone, sufficient accuracy can be obtained,

ON SURVEYING WITH THE THEODOLITE.

SECTION VI.

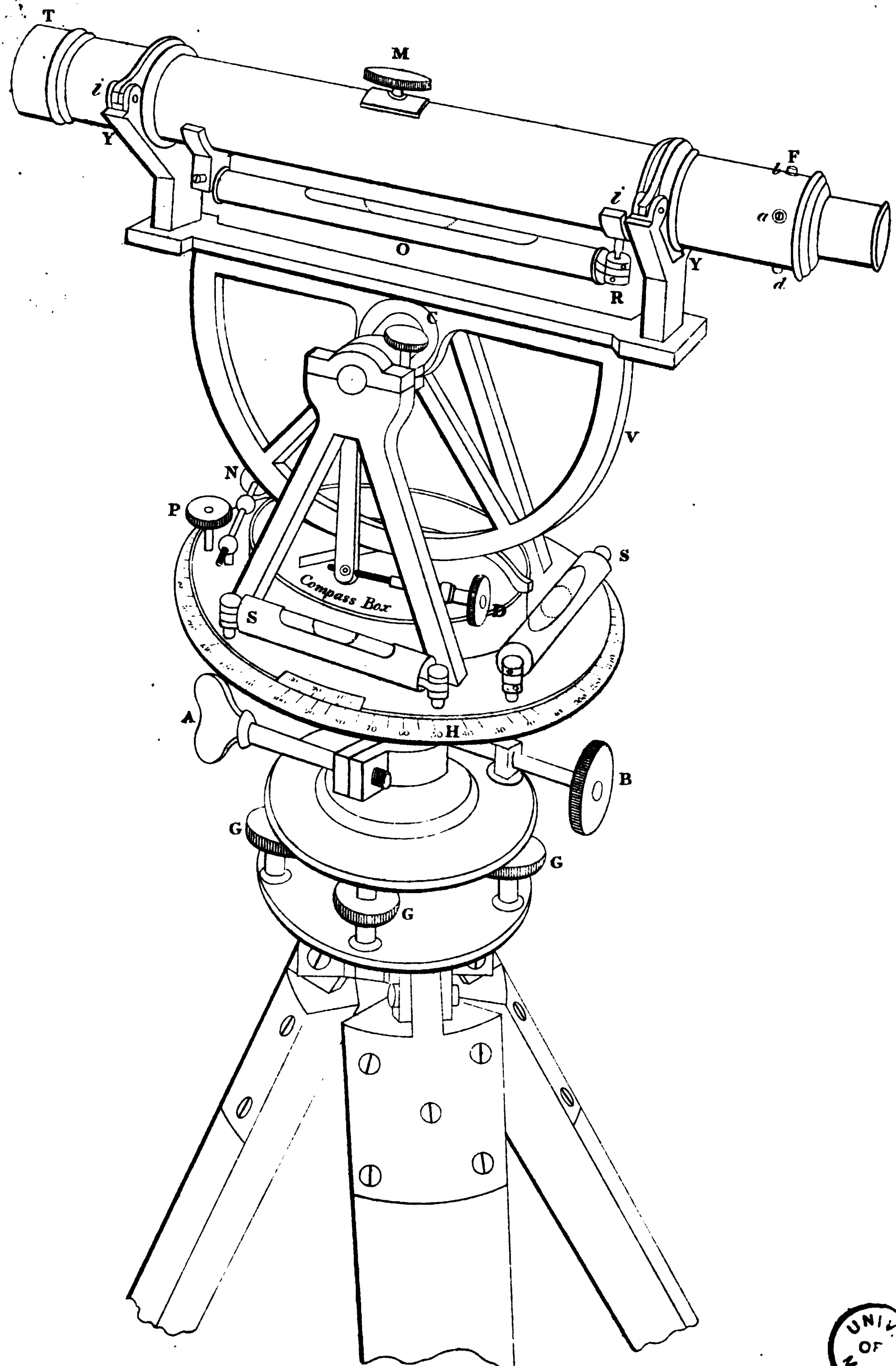
A DESCRIPTION OF THE THEODOLITE—ITS ADJUSTMENT IN THE FIELD—TAKING ANGLES—VERNIER SCALE.

THE student who has carefully considered what is contained in the preceding sections, must already have acquired some knowledge of surveying. It has been observed that the principles of the art are the same, whatever may be the extent of work to be performed, or the kind of instrument used; and this he will find to be the case as we proceed.

The Theodolite (plate VII.) is the most perfect instrument used in surveying, as it gives the horizontal angles without reduction.* It is composed of a telescope, T F; with a spirit level, O, attached. A vertical arc, V, for measuring angles of elevation and depression. A plate, termed the horizontal circle H, having upon it cross spirit levels, S,S. A compass. Parallel plates, with four vertical screws, G, for levelling the horizontal circle. A clamping screw, A, to prevent the horizontal circle from moving round. A tangent or micrometer screw, B, to turn the instrument slightly, after being clamped by the screw, A. A screw, P, for fixing the upper or index plate

* An explanation of the difference between angles taken with a theodolite or compass, and those measured with a sextant or other reflecting instrument, will be found in treating of the pocket sextant.

PLATE VII.

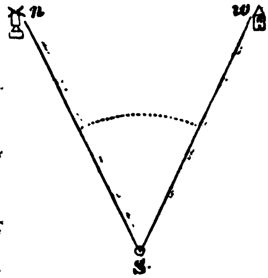


to the horizontal circle, H, which may then be slightly turned for a nice adjustment of the telescope to an object, by means of the micrometer screw, N. The instrument is mounted on three stout legs.

When in perfect adjustment, the horizontal circle is truly level. The vertical arc is in a plane, perpendicular to the horizon. The line of sight, or of collimation (*i. e.*, axis of the telescope), must be true, and the level attached to the telescope must be parallel to the line of collimation.

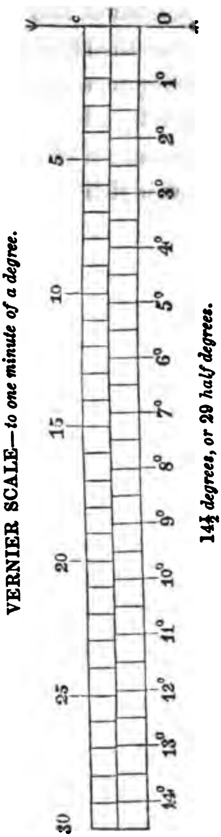
The theodolite is set up thus:—Place it over the station mark, spread the legs to about three feet apart, and move them until the *vertex* of the legs is exactly over the mark. A small stone dropped, or a plummet suspended from a hook, immediately under the vertex, will indicate when this is effected. Being satisfied as to the position of the instrument, press the legs firmly into the ground, and proceed to level it. Two spirit levels are generally fixed to the upper plate of the instrument, at right angles to each other, and the four parallel plate screws, G, act upon this plate. Bring one of the spirit levels into a position parallel, if I may say so, with two of those screws that stand opposite or diagonally to each other. Now, by raising one screw, and lowering, at the same time, its opposite, the position of the horizontal circle will be changed. Continue working these screws until the bubble of the spirit level acted upon rests in the middle of the open space: then work the other pair of screws, until a similar effect is produced upon the other spirit level. The adjustment of the latter will, however, throw the other level somewhat out, rendering a return to it necessary. The horizontal circle is not truly level, or parallel to the horizon, until the bubbles of both spirit levels stand in the middle of the open spaces during a revolution of the instrument.

An angle is measured with the theodolite thus:—S is the station of the instrument: required the angle between the windmill n and the spire w. Plant the theodolite over the station point, as directed above, carefully attending to all the instructions just given. Make zero of the vernier scale to coincide with zero of the horizontal



circle, and fix them so by tightening the screw P. Place the intersection of the hairs in the telescope on the windmill n, and fasten the clamping screw, A; then if the object n is not found to be exactly covered by the point where the hairs cross each other, turn the micrometer screw, B, which will enable you to fix it with the utmost precision. This effected, loosen the screw, P, which will release the index or vernier plate from the horizontal circle; then turn the upper part of the instrument until the cross hairs cut the object w. The vernier micrometer screw, N, enables this to be done very exactly, on tightening the screw, P. Then the number of degrees and minutes passed over by the vernier, or index, shows the measure of the angle.

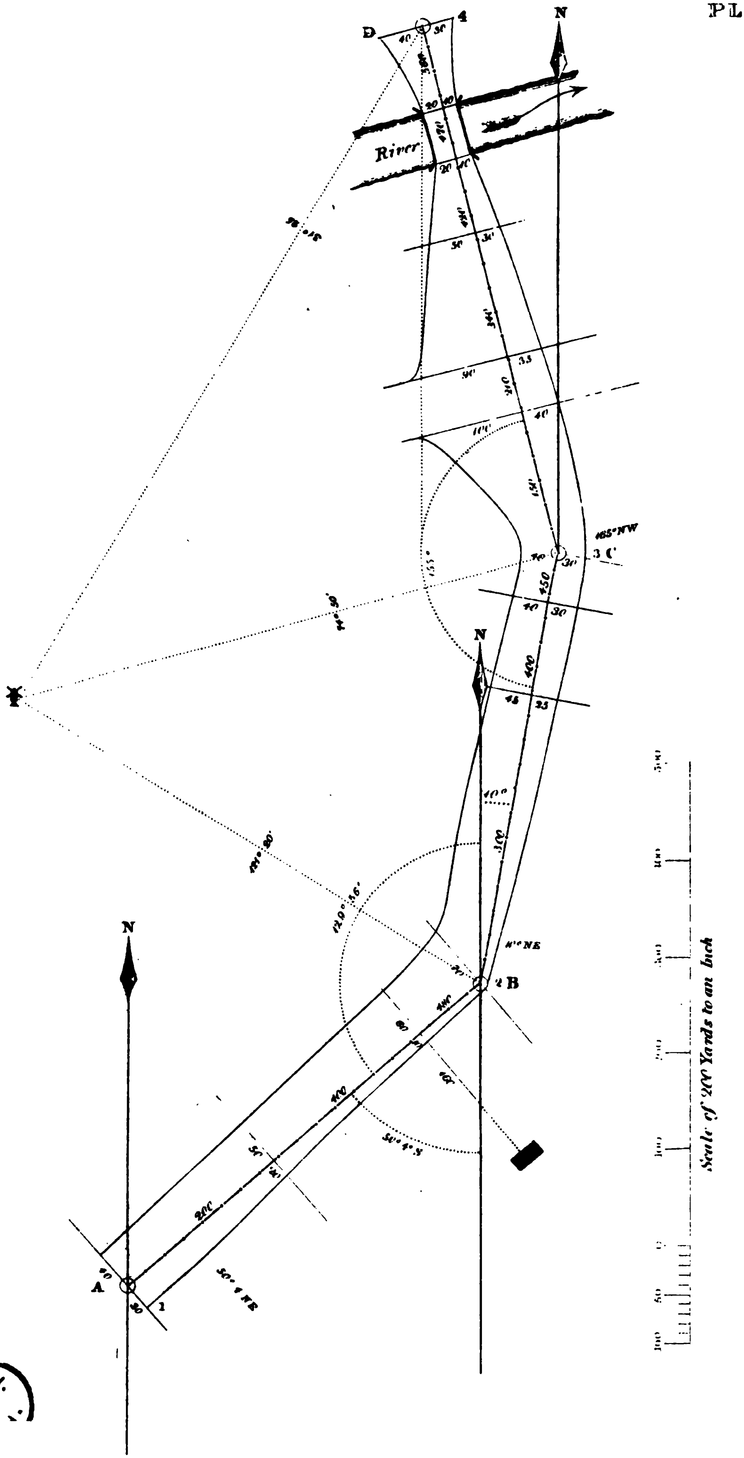
The vernier scale must now be noticed. The horizontal circles of ordinary theodolites are divided to half degrees, and are generally numbered from zero to 360°. Now, without such a contrivance as the vernier, we can only guess at the number of minutes, when the index does not exactly agree with one of the subdivisions; but, by means of a vernier, we are enabled to read off an angle on the circle of an ordinary theodolite to a single minute; and may, if the horizontal circle be very large, read off to twenty seconds with the greatest certainty.



The construction of this ingenious contrivance is simple. Suppose we want to read off to one minute.—Take the length of 29 half degrees on the horizontal circle, and divide that distance into 30 equal parts; this forms the vernier, which is marked for convenience, 5, 10, 15, 20, 25, 30, from one end, or the zero. Place the vernier to the horizontal circle, so that zero of the former may be in contact with zero of the circle; then the last division, marked 30, of the vernier will, of course, agree with 14½°, or 29 half degrees of the circle. And the proportion of each division of the vernier will be to a division of the circle as 29 to 30. If the zero of the vernier be moved from the zero of the circle, then the first coincidence that takes place between a division of the vernier with one on the circle, indicates the number of minutes passed over. To read off an angle on the horizontal circle, use a magnifying glass, and notice how many degrees have been passed over by the zero of the vernier: for example, let us suppose that the arrow at zero of the vernier has passed the 21st degree of the circle; then, for the number of minutes in addition, look along the vernier, until one of its divisions is found to agree exactly with a division on the circle below it. You find, we will suppose, that the 14th division of the vernier does so: then the angle is 21° 14′.

A careful and minute description of the various parts of the theodolite, with instructions for their adjustment before proceeding to the field, will be found further on; aided by which, an intelligent person may, with a little practice, rectify every derangement to which the instrument is liable.

PLATE VIII.



SECTION VII.

TRAVERSING WITH THE THEODOLITE AND CHAIN, AND PLOTTING THE SURVEY.

THE process by which roads, rivers, woods, &c. are surveyed is termed *traversing*; the method of performing which I shall now describe, taking the survey of a road as an example.

The following implements are required:

A measuring chain.

Ten arrows.

Two staves, for placing as marks at the stations.

A field-book, for registering the observations and measurements.

Land surveyors universally use the Gunter chain, of 66 feet, divided into 100 links; which is very convenient when the contents of an estate or parish are to be given in acres, roods, &c.: but for our purpose, a chain 100 feet long is to be preferred, the object being to obtain lineal, and not superficial, measure. The 100 feet chain is divided into links of one foot each; and certain brass marks fixed on it, at ten feet distance from each other, show at once any number of feet less than 100. The arrows are stout pins of iron wire, about twelve inches long. The field-book, of the size of a common memorandum book, has upon every alternate page two lines drawn lengthwise down the middle, at about three-quarters of an inch apart. The blank page adjoining is used for making notes.

Let A (plate VIII.) be the point upon a road for commencing a survey with the theodolite. Set up the instrument very exactly over the point marked, level it carefully in the manner already described, and place zero of the vernier to agree with zero of the horizontal circle; then, by means of the screw, P, fix the two plates together. Now turn the instrument on its axis, until the marked end of the needle settles exactly at the division in the compass-box at N, or north, marked 180, and tighten the clamping screw, A; then, if the needle does not accurately agree with the 180 in the compass-box, use the micrometer or tangent screw, B, which will adjust it to the greatest nicety.

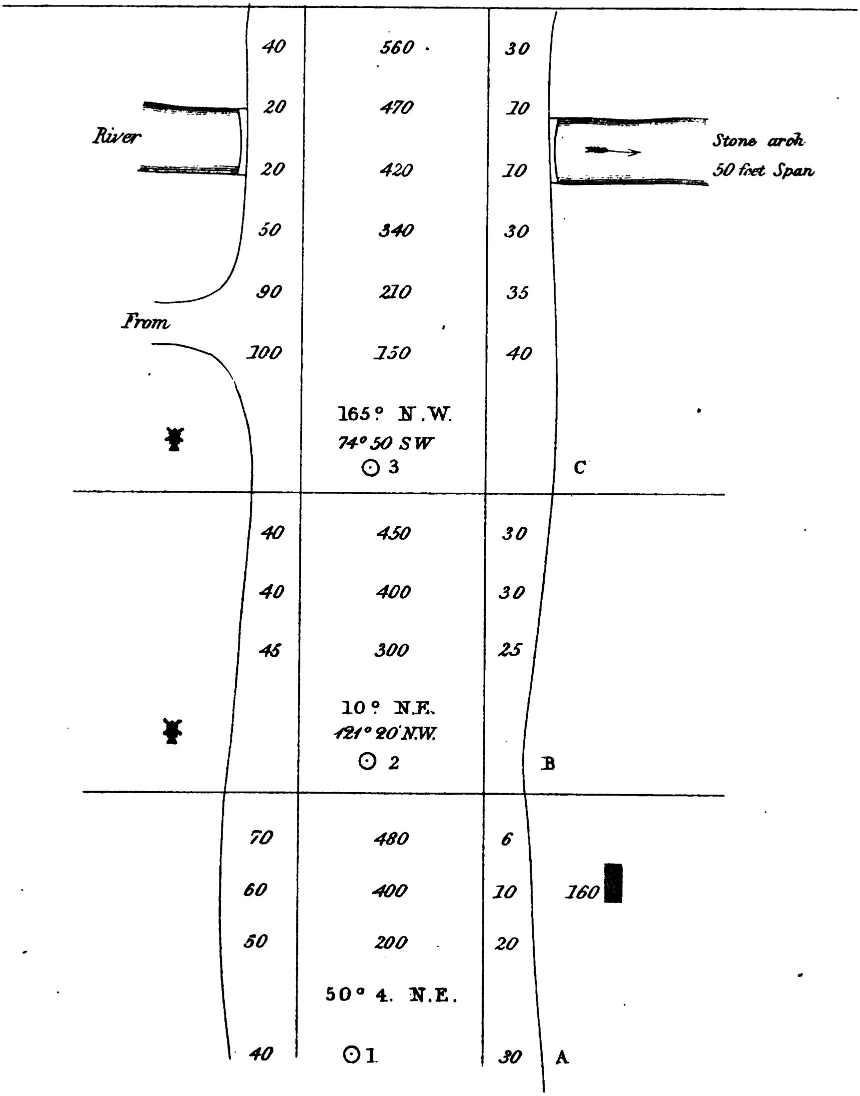
Place a staff or bandrol at the point B,* where the road makes a bend, and examine your instrument again to see, 1st, that the index or zero of the vernier corresponds with zero of the horizontal circle; 2nd, that this circle is truly level; 3rd, that the needle points exactly to the division at N; and, lastly, that the clamping screw is firm.

To measure the angle which the line A B forms with the meridian A N, loosen the screw, P, which connects the vernier plate with the horizontal circle, and turn the vernier plate, with the upper portion of the theodolite, on its axis; continue this until the staff at B is seen through the telescope: then tighten P, and turn the micrometer screw, N, at the same time raising or depressing the telescope as much as may be requisite. Fix the intersection of the hairs in the telescope precisely on the *bottom* of the staff at B, and refer to the vernier for the exact measure of the angle, that a line from A to B forms with the meridian, which meridian is represented by the direction of the needle.

* The letters A, B, &c., are not necessary in surveying, to mark the stations on a road; ⊙ 1, ⊙ 2, &c., are sufficient for that purpose. Letters are used here to facilitate the descriptions.

Form of Register
or

FIELD BOOK.



Began at Mile stone going towards

On examination, we find that the zero of the vernier is something past the 50th degree of the circle; and looking along the vernier, through the magnifying glass, it appears that the 4th division on it agrees with a division of the circle. Thus, the bearing is 50° 4′; and as we perceive, looking at the needle, that ⊙ B lies to the right, or eastward of north, we put down 50° 4′ N. E., ⊙; the latter mark being to distinguish the station angle or bearing, as the case may be, from any other angle or bearing that may be observed at the same time. The first entry in the field-book is made at the bottom of the page, proceeding upwards. (See specimen of a field-book, plate IX.)

The next step is to measure the distance from A to B. To do this, an assistant takes one end of the chain, and proceeds towards B, until desired to stop by the person holding the other end. The latter places himself over the point where the instrument stood, and motions the chain leader, who is facing him, to move right or left, until he is exactly in a line with a staff at B. The chain is then drawn tight, and left on the ground while any off-sets, that may be necessary, are taken. Off-sets are measurements laterally from the chain, and usually perpendicular to it, to determine the distance of a house, fence, gate, &c., from the chain line. For instance, the breadth of the road at A (plate VIII.) is found by measuring, or taking an off-set at right angles with the chain line to the fences, on each side of that point, namely, to the right, 30 feet, and to the left, 40; which are entered in the field-book at A. Off-set measurements may be made by pacing, with a wooden rod, or a measuring tape, according to the degree of accuracy required. Pacing does very well for military plans, and the eye is sufficient guide for the direction, so as to go perpendicularly to the chain-line.

Let me observe here, that the space between the two

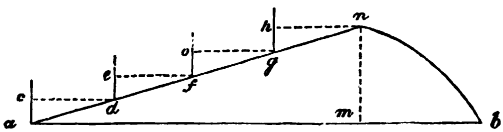
ruled lines of the field-book represents the chain. Bearings or angles taken during the survey, together with all distances measured between stations, are entered in this space; but all off-sets from the chain are put down outside the ruled lines.

To proceed with the measurement towards B. The chain leader has ten arrows, one of which he sticks into the ground at the end of the chain, or makes a cross if the road is hard, and lays the arrow down: he then draws the chain forward, giving it a cast to the right, so as to keep it from disturbing the arrow he has placed. When the chain follower comes within a few feet of the arrow placed at the end of the first chain, he calls "Halt," places the leader in line with B, and takes up the arrow. At two chains, or 200 feet, from A, a second off-set is taken, namely, 20 feet on the right, and 50 feet on the left; which are entered, as seen in the field-book. Thus the measurement proceeds—the leader always depositing an arrow at the end of every chain, which is taken up by the follower. At the end of ten chains, the leader will have expended all his arrows, which have become transferred to the follower. When the eleventh chain is measured, the latter runs forward, and restores the ten arrows to the leader, who should count them to see that he has ten, and place one, to mark the eleventh chain; 1000 is then entered in the chain column, and so on to 2000, 3000, &c.; and on arriving at the end, he has only to count the arrows in his hand, adding whatever number of feet are indicated by the brass marks upon the chain; and in this way he will rarely make any mistake.

At 400 feet, there is an off-set to a house standing at the distance of 160 feet from the chain. Be it observed, that all off-sets are to be put down at their distance from the chain: here, for example, we have 10 feet to the fence,

and 150 from thence to the house; but we enter 160, the distance of the house from the chain.

Let us here remark that lines laid down upon a plan are always horizontal lines; that is, they are of the same length as if they were measured between points on the same level. Hence, in all surveys, every line measured upon sloping or undulating ground, must be reduced to its corresponding horizontal length, before it can be laid down on paper.



The above diagram represents a section of a hill, standing on the base *a b*. Now, it is evident that a curve line, *a d f g n b*, describing the form of the hill, is longer than the line, *a b*; and, therefore, as the distance, *a b*, is all that can be allowed in a plan, if a surveyor measures the curve surface of the hill, he must of necessity reduce it to the horizontal distance.

There are various ways of reducing sloping lines to horizontal ones; but I believe that in practice the following simple method is commonly adopted:—

We will suppose that the slope *a n*, is to be measured downwards. One person holds an end of a tape at *n*, while another stands with a staff at *g*, 30, 40, or 50 links down the slope, according to its steepness; the portion of the tape used is then to be drawn tight, while held horizontally, represented by the line, *h n*; an arrow is then placed at *g*. In this way a succession of short horizontal lines, *h n*, *o g*, *e f*, and *c d*, will give the length of *a m*, the horizontal distance corresponding to the hypothenusal line, *a n*.

The measurement of the first station line being com-

pleted, the theodolite, with the vernier clamped at 50° 4′, is set up at ⊙ 2 (B), care being taken to place it vertically over the hole in which the staff stood, which may be ascertained by dropping a stone from the vertex of the legs of the instrument, or by a plummet, as already mentioned; a staff is then to be planted at the next bend of the road, C, and the instrument adjusted. The telescope is now to be directed back on a bandrol placed at A (the adjustment upon A being effected by means of the screw, B, plate VII.), and, with the vernier still at 50° 4′, the instrument must be clamped by means of the screw, A. The vernier plate is then to be released, and the telescope adjusted on a bandrol at C, the third station: the reading of the vernier will then be 10°; for, previous to unclamping the vernier plate, the reading was 50° 4′, and 129° 56′ completed the 180, bringing the telescope to agree with the meridian line; the new reading is therefore the amount of the angle N B C, or 10°. Clamp that angle, remove the theodolite to C, and adjust the telescope on B; then release the vernier plate, and direct the telescope on D, when the reading will be 165°, viz., 155° added to the 10°; and thus the survey proceeds.

When traversing, angles should be taken to any remarkable objects that may be visible from several stations, not being more than half a mile or so distant, that the intersections may not be too acute, as a check upon the work; for afterwards, in plotting, when the bearings of an object unite in a point, the proof of accuracy is complete. Whenever check angles are taken, it is usual to enter them in the field-book before inserting the forward station angle, to avoid mistake; but it is better to place this mark (⊙) at all times against the angle which gives the direction of the road, or the line on which you measure. The lines from B, C, and D, converging upon a windmill, represent

check bearings, which, in order to avoid confusion, have not been noticed before.

It will be perceived that, after the adjustment of the needle at the first station, it becomes no longer necessary, except to point out the directions of the several station lines; indeed, there is no necessity for adopting the magnetic meridian to work from, as any line of a survey will equally answer the purpose; for instance, referring to plate VIII., we might begin the survey by measuring the line A B. and setting up the theodolite at B, measure the angle A B C ⊙ 139° 56′; then adjusting the theodolite at C, and having directed its telescope back on B, with the index at 139° 56′, unclamp and turn the vernier plate, until the telescope is fixed on D, when the reading on the horizontal circle would give the angle which the line C D forms with the line A B; and thus the line A B becomes the working meridian to which all the angles have reference; while the compass needle serves to denote the cardinal directions of the station lines.

In order to be able to resume an incomplete survey, a mark must be made at the last station by cutting a cross in the sod, or driving a strong peg into the ground. And it is necessary, both on beginning and ending a day's work, to take angles between the back or forward stations, and any two fixed points that may be visible.

TO LAY DOWN OR PLOT THE SURVEY UPON PAPER.

It will readily be perceived that angles measured accurately to minutes of a degree with the theodolite will avail us little, unless we have the means of plotting them with equal accuracy; and this we are enabled to do by using a protractor, furnished with a vernier, which may be either of a circular or semicircular form. Let us suppose the

learner to be provided with one of the latter shape, such as he will find described in a subsequent section.*

Draw a line, N A, upon the paper, to represent the meridian of A, (see plate VIII.); mark a point upon it for the first station, A. Apply the protractor, so that its diameter shall lie along the meridian line, having its centre at the station-point, and set the vernier to the first bearing entered in the field-book, namely, 50° 4′—or this may be done previous to placing the protractor: draw a fine line on the paper along the arm of the protractor from the first station, which line defines the direction of station 2 (B), lying 50° 4′ N.E. of the meridian.† Next, from any scale of equal parts selected for the survey, take in the compasses 480, being the whole length measured to ⊙ 2,‡ which distance, taken along the line just drawn, fixes ⊙ 2 (B). Through this point, draw a line, N B, parallel to N A, for the meridian of ⊙ 2. Now set the protractor to 121° 20′, apply it to the line N B, and draw an indefinite line in a N.W. direction, being the check bearing to a windmill: which done, set the protractor to 10°, and draw the line, B C, measure 450 from your scale, and fix the point, C,

* For plotting traversing surveys on a small scale, a circular pasteboard protractor has long been in use amongst the Ordnance surveyors: it is made by describing a circle with a radius of five inches, and dividing the circumference to one-fourth of a degree. The zero of this protractor being made to agree with the meridian on paper, to which all the angles of a survey have reference, a parallel ruler is stretched across its diameter to the opposite corresponding angle, and then moved forward to the point from whence the bearing is to be drawn. For surveys on a very large scale, however, the semicircular brass protractor, with a vernier, is necessarily more accurate. Pasteboard protractors, printed from a plate for the use of the Ordnance surveyors, may be purchased at the establishment of Messrs. Troughton and Simms, 138, Fleet Street.

† The learner will bear in mind that the meridian here spoken of is not necessarily the magnetic meridian, but may be any line assumed as a working meridian.

‡ A convenient method is to divide a slip of drawing paper very accurately, according to the intended scale, and apply it to the chain line: this is an expeditious mode, but less exact than taking distances from a diagonal scale with a pair of compasses.

⊙ 3. Make N C parallel to N B, and having set the protractor to 74° 50′, the check bearing on the windmill, draw a line which will intersect the check line from B, and fix the position of the windmill. The protractor is then set to 165°, applied to the line N C, and the distance to D being laid off, a line parallel to C N is drawn through D; when, if a check bearing 31° 25′ is found to meet at the windmill, a proof is afforded of the accuracy both of the surveying and plotting thus far.

The station lines of the survey having been thus laid down, the off-sets are then to be plotted; and now a *plotting* scale, or slip of paper divided to a scale, is extremely useful.* Beginning at ⊙ A, lay off 200 and 400 along the line A B, then turn your slip of paper, so as to be at right angles to the line, A B. and at the point, A, set off 40 and 30, as seen in the plan; then at 200, again use the slip scale, and mark off 50 on the left, and 20 on the right, of the line A B; at 400, 60 and 10. Join these points of the cross measurements, or off-sets, and the boundaries of the road will be correctly shown.

The road in plate VIII. being accurately drawn to a scale of half an inch to 100 feet—namely, the large diagonal scale on the ivory protractor—a comparison of it with the description given, will, it is hoped, render the whole process perfectly intelligible.

It may here be observed, that when a survey on a large scale is made, it is usual to note the kind of fence which borders a road, and gates, large trees, &c., are put in; for these, and various other objects noticed in a plan, certain conventional signs are used, for which, see section on plan-drawing.

* The ivory protractor, with lines for adjusting to a meridian, such as we use for plotting in the field, makes a good plotting scale.

EXAMPLE OF TRAVERSING.

The following example of traversing is taken from Mr. F. W. Simms's treatise on instruments;* and I recommend it to the student's attention, as highly useful in showing how a check is maintained over a road survey, so as to preclude the possibility of error.

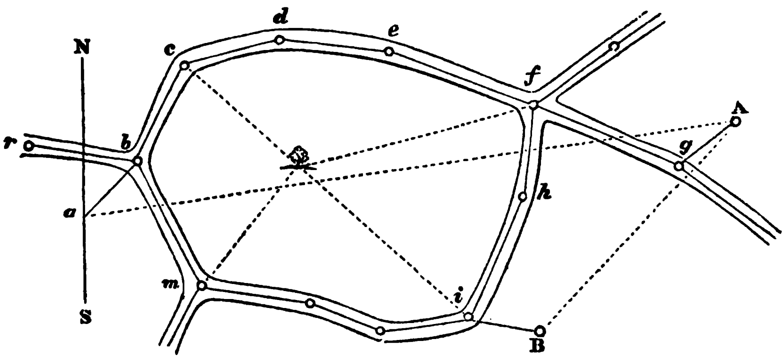
Let the diagram in page 39 represent a survey of roads to be performed with a theodolite and chain. Commencing on a conspicuous spot, *a*, near the place where two roads meet, the theodolite must be set up and levelled, the upper and lower horizontal plates clamped at zero, and the whole instrument turned about until the magnetic needle steadily points to the N. S. line of the compass-box, and then fixed in that position by tightening the clamping screw A, (see plate VII.). Now release the upper plate, and direct the telescope to any distant conspicuous object within or near the limits of the survey, such as a pole purposely erected in an accessible situation; that it may be measured to, and the instrument placed upon the same spot at a subsequent part of the operation, as A and B, and after bisecting it with the cross wires, read both the verniers of the horizontal circle, and enter the two readings in the field-book; likewise, in the same manner, take bearings, or angles, to all such remarkable objects as are likely to be seen from other stations, as the tree situated on a hill; and lastly, take the angle to your forward station, *b*, where an assistant must hold a staff for the purpose, on a picket driven into the ground,† in such a situation as will enable you to take the longest possible sight down each of the roads that meet

* A Treatise on the principal Mathematical Instruments employed in Surveying, Levelling, &c. A very useful book.

† A picket should always be left in the ground at every station, in order to recognize the precise spot, should it afterwards be found necessary to return to it again.

there. In going through the above process, at this and every subsequent station, great caution must be used to prevent the lower horizontal plate from having the least motion after being clamped in its position by the screw, A.

Next measure the distance from *a* to *b*, and set up the instrument at *b*; release the clamp-screw A *only*, not suffering the upper plate to be in the least disturbed from the reading it had when directed at *a* to the forward station *b*; with the instrument reading this forward angle, turn it bodily round, till the telescope is directed to the station *a* (which is now the back station), where an assistant must hold a staff, tighten the clamp-screw, A, and by the slow-motion screw, B, bisect the staff as near the ground as possible, and, having examined the reading, see that no disturbance has taken place, release the upper plate, and, setting it at zero, see if the magnetic needle coincides, as



in the first instance, with the N S line of the compass-box; if it does, all is right; if not, an error must have been committed in taking the last forward angle, or else the upper plate must have moved from its position before the back station had been bisected; when this is the case, it is necessary to return and examine the work at the last station.

If this is done every time the instrument is set up, a constant check is kept upon the progress of the work; and this indeed is the most important use of the compass. Having thus proved the accuracy of the last forward angle, release the upper plate, and measure the angles to the stations *m* and *r*, and, as before, to whatever objects you may consider will be conspicuous from other places; and lastly, observe the forward angle to the station *c*, where the theodolite must next be set up, and measure the distance *b c*.

At *c*, and at every succeeding station, a similar operation must be performed, bisecting the back station with the instrument reading the last forward angle; then take bearings to every conspicuous object, as the tree on the hill, the station A, &c., which will fix their relative situations on the plan, and they afterwards serve as fixed points to prove the accuracy of the position of such other stations as may have bearings taken from *them* to the same object; for, if the relative situations of such stations are not correctly determined, these bearings will not all intersect in the same point on the plan. The last operation at each station is to measure the forward angle. In this manner proceed to the stations *d*, *e*, *f*, *g*, &c., and having arrived at *g*, measure the angle to the pole A, as to a forward station, and, placing the theodolite upon that spot, direct the telescope to *g*, as a back station, in the usual way; this done, release the upper plate, and direct the telescope to the *first* station, *a*, from which A had been observed, and if all the intervening angles have been correctly taken, the reading of the two verniers will be precisely the same as when directed to A from the station, *a*; this is called *closing* the work, and is a test of its accuracy, so far as the angles are concerned, independent of the compass needle. If the relative situation of the conspicuous points, A, B, &c., were previously fixed, there would be no necessity to have recourse

to the magnetic meridian at all, as a line connecting the starting point, *a*, with any visible *fixed* object, may be assumed as a working meridian; and, if it be thought necessary the reading of the compass needle may be noted at *a*, when such fixed object is bisected; and upon the theodolite being set to the reading of this assumed meridian, at any subsequent station, the compass needle will also point to the same reading as it did at first, if the work is all correct, and no local attraction influences the compass.

While the instrument is at A, take angles to all the conspicuous objects, particularly to such as you may hereafter be able to close upon, which will (as in the above instance) verify the accuracy of the intervening observations; having done this, return to *g* and *f*, &c., and proceed with the survey in the same manner as before, setting the instrument up at each bend in the road, and taking off-sets to the right and left of the station lines; arriving at *i*, survey up to, and close upon, B; then return to *i*, and proceed from station to station till you arrive at *m*, where, if the whole work is accurate, the forward angle taken to *b* will be the same as was formerly taken from *b* to *m*, which will finish the operation.

SECTION VIII.

GENERAL OBSERVATIONS ON SURVEYING.

SURVEYING may be defined, the art of representing a country, or any portion of the earth's surface, upon paper, in such a manner that we may be able, by means of a scale, to measure the horizontal dimensions of its features; as territorial boundaries, lakes, rivers, forests, roads, &c.

The foundation of every survey is a base line; and upon the accuracy with which the length of the base is obtained, the correctness of the entire survey must depend.* The measurement of a base, then, is not only the primary, but also the most important work to be performed. Various methods have been pursued to effect this object.

Previous to the measurement of the Hounslow base, deal rods were considered very good for the purpose, and had been extensively used on the Continent; but experiments made on that occasion proved their unfitness, owing to the uncertainty of their expansion; perhaps, however, our more humid climate may have produced a greater effect

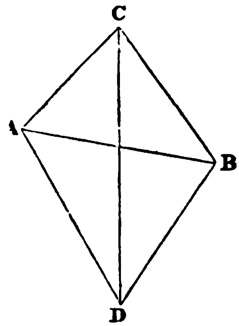
* The length of the base measured on Hounslow Heath, for the grand Trigonometrical Survey of England, in 1784, was, when reduced to the level of the sea, 27404·1037 feet. Three modes of measuring were tried, viz., with deal rods, with a steel chain of peculiar construction, and by means of glass tubes. The uncertain expansion and contraction of the deal rods, was found to produce a very fallacious result. The steel chain does not appear to have had a fair trial upon this occasion. The method proposed with glass tubes obtained the preference. Accordingly, the measurement took place with these, and was conducted in a scientific manner, with all the care due to so important an operation. In 1791, a careful measurement of the same base was made with the improved steel chain, which only differed from the original one performed with glass tubes, by about 2¾ inches. Subsequently, in 1794, a base of verification was measured on Salisbury Plain, which varied only about 3½ inches from its computed length.

upon them, than the comparatively dry atmosphere of situations where they had before been tried; and it appears, from the account of the operations on Hounslow Heath, in 1784, that the season was a very wet one. On the whole, if I may presume to offer an opinion in the matter after their condemnation by men of so much science, I should still advise the use of deal rods under other circumstances, and where glass tubes and steel chains, such as were used on the occasion above mentioned, with all the vast preparation made for their application to the object in the most perfect manner, cannot be had; and, more than all, when the contemplated survey is not of the most important character.

In ordinary surveys, it is not necessary to enter into calculations, on account of the sphericity of the globe; nor indeed into many other niceties, such as would be imperative, were the object to measure an arc of the meridian, or perform any other grand geodesical operation. On common occasions it suffices to consider the earth as a plane or flat surface, and all the sides of the triangles as right lines, instead of curves.

The ground having been selected for measuring a base, and this operation performed with all the accuracy the means will admit of, the next step is to choose the most eligible points for carrying on the triangulation—a survey being conducted by means of a series of triangles, of which the base line forms one side of the first. With this view, conspicuous situations are fixed on, as the tops of hills, church towers, &c. These primary stations ought generally to be of a distance from each other, bearing some proportion to the length of the base and extent of the proposed survey. For instance, if the base be two miles, and extent of the survey 15 or 20 miles, the sides of the triangles may be from two to four miles; much, however, must always depend on the relative position of commanding points for

stations, and on the two first triangles of the survey. For example:—Suppose A B to represent a base line, and that C and D are eligible stations, forming two triangles, A C B and A D B. Knowing the length A B, and the angles at A and B, the length of C D is found by an easy calculation in trigonometry; and that line becomes nearly as good a base, in point of measurement, as A B, while it possesses the advantage of being longer, and thus enabling us to increase the sides of our triangles.*



Wherever the instrument is set up, observations should be taken to all remarkable objects; these, being repeatedly intersected, furnish a check on the work as it proceeds, and their several positions are furthermore determined for future use.

When possible, all the angles of the principal triangles should be observed; then, as the sum of the three angles ought to be 180°, we are enabled to judge of the accuracy of the observations, and in some degree of the perfection of the instrument used.

The sides of all the principal triangles should be *calculated*, and laid down by means of beam compasses—as laying down by the *sides* is always more correct than by the *angles*. In triangles on a large scale, an error of a single minute, in protracting an angle, would sensibly affect the length of the sides.

As it is impossible to avoid some degree of error in taking angles, we should endeavour so to order our opera-

* This method of obtaining a longer base, as it may be termed, becomes useful when a base is measured on low ground between hills, as must frequently be done; such situations being often level, and suitable for the purpose.

tions that the error may have the least possible influence on those sides, the exact measure of which is the object to be obtained.

When the base cannot be equal to the side or sides sought, it should be as long as possible; and the angles at the base should be nearly equal.

Sometimes it occurs that the three angles of a triangle cannot be observed; in that case, the angle obtained by intersection should be as near as possible a right one. Acute intersections are at all times to be avoided.

The fewer the principal stations, the less will be the labour of the survey; it will also be more accurate, and less liable to mistakes while in the field, or errors when plotting the work at home.

Military men generally fill in the principal triangles by means of the surveying compass, when the survey is not required to be minutely exact in all its details.

These general observations might be multiplied to an unlimited extent; and yet, after all, when a survey is to be undertaken, the surveyor must depend chiefly on his own judgment, to lay out the work to the greatest advantage, according to the nature of the country, and other circumstances that will affect his operations.

SECTION IX.

METHOD OF CONDUCTING AN ORDINARY SURVEY, WITH A THEODOLITE AND CHAIN.

It may now be of service, if I proceed to furnish an example of the most simple manner in which the survey of a tract of country may be commenced and carried forward. I shall suppose the survey such as might be wanted for military purposes, and that a small theodolite and common measuring chain are to be used. (Plate X.)

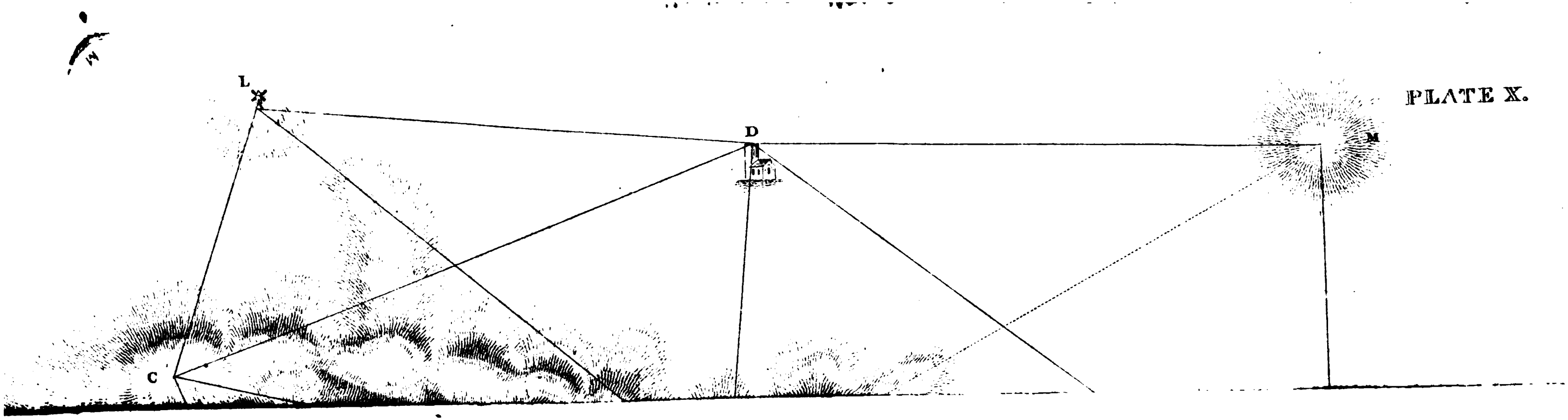
The selection of a base line is the first consideration; and on examination, the direction of A B, along a piece of level ground, is found the most eligible. The next object is to choose commanding points for stations, so situated with respect to each other that good triangles may be formed; that is, sufficiently wide apart, and forming angles not too acute. These important matters being arranged, the base, A B, must be carefully measured three times over, and the mean taken, which is 3574 feet.

Marks, such as small flags, having been placed at C, E, and F, the most favourable points on the ridge running parallel to the river; also at H and G: the theodolite is set up at A, and the following angles taken, namely, C A E, CAF, CAB, BAG, and BAH. These may be entered in the field-book thus:—

At A.

From	C to E,	65° 50′	(Angle	C A E.
	C to F,	96 40	„	C A F.
	C to B,	126 45	„	C A B.
	B to G,	22 25	„	B A G.
	B to H,	80 10	„	B A H.)

PLATE X.



The instrument is then taken to the other end of the base, and angles are observed at B.

At B.

From A to E,	40° 20′	(Angle	A B E.
A to F,	100 2	„	A B F.
G to H,	31 40	„	G B H.
G to A,	64 0	„	G B A.)

It should be observed, that when time permits, it is usual to take all such angles three times over, each time turning the circle of the theodolite, for greater correctness, and as a check against error. In this case, an entry would be made thus:—

At B.

	1st Obs.	2nd Obs.	3rd Obs.	Mean.
From A to E	40° 20′	40° 19′	40° 21′	40° 20′
A to F	100 2	100 1	100 3	100 2

With respect to the circle of the instrument, you may begin to work from any part of it; by which, should the dividing not be very perfect, the errors compensate each other, and to save time in the field, enter the readings as you obtain them from the circle, and work out the quantity for each angle at home. Suppose you commence taking angles, with the index showing 50° 10′, the entries at B would be thus, to agree with the preceding example:—

Index at 50° 10′.	From A to E.		From A to F.	
	1st observation	90° 30′	1st observation	150° 12′
	2nd ditto . .	90 29	2nd ditto . .	150 11
	3rd ditto . .	90 31	3rd ditto . .	150 13
	Mean . . .	90 30	Mean . . .	150 12
	Deduct . . .	50 10	Deduct . . .	50 10
		40 20		100 2

The requisite angles having been observed from each end of the base, the instrument is moved to E, and angles taken, namely:—

At E.

From A to C,	59°	10′	(Angle A E C.
A to L,	87	0	„ A E L.
A to D,	142	30	„ A E D.)
A to M,	199	20	
A to F,	226	40	
A to B,	281	15	

Next move to C.

At C.

From L to D,	51°	20′	(Angle L C D.
L to E,	84	5	„ L C E.
L to A,	139	5	„ L C A.)

The instrument is then taken to F.

At F.

From B to A,	49°	53′	(Angle A F B.
B to E,	75	30	„ E F B.
B to D,	103	2	„ D F B.
B to M,	155	12	„ B F M.)

After which, angles are observed from other stations.

Previous to plotting, I recommend a diagram or figure to be drawn, representing the base line, and the several triangles; of these, it is a good plan to make a list, thus:—

Triangle A E B.			*Triangle* A C E.			*Triangle* A B F.		
Angle A,	60°	55′	Angle A,	65°	50′	Angle A,	30°	5′
B,	40	20	C,	55	0	B,	100	2
E,	78	45	E,	59	10	F,	49	53
	180	0		180	0		180	0

To lay down the triangles:—First draw a line on the paper, and take from the scale you intend to use, 3574, for the number of feet in the base; lay off this distance along the line, and one end of the length so marked on the line will be A, the other B.

The next consideration is whether the triangles shall be laid down by the sides or the angles; if by the sides, their lengths are worked out by means of plane trigonometry, and then laid down; for example: In the triangle A B E, one side, namely the base, A B, is given, and the three angles; by means of which we are enabled to find the other two sides, A E and E B, by an application of the first case of trigonometry. The distances so found have then only to be taken from the same scale as the base, and the triangle, A E B, is easily constructed. Again, in the triangle, B E F, we have the side, E B (as just found), and the angles, to find E F and B F. Also in the triangle, A C E, the side, A E, has been found, which, with the angles, give A C and C E. The other triangles are obtained in the same way. Thus, every side whose length is found becomes a base line for a succeeding triangle; and in this way a succession of triangles may be carried over the face of a country.

But in a survey of small extent, and especially when time, as during warfare, becomes an object of importance, the triangles may be protracted by the *angles*. Indeed, when the sides of the triangles do not exceed two or three miles, and the scale not more than four inches to a mile, a good protractor of five or six inches radius enables us to lay down the triangles with sufficient accuracy and great despatch.

To commence then protracting by the angles: We find that, having the theodolite placed at A, our first set of angles was measured *from* C, to E, F, and B; therefore,

the first step now must be to fix the direction of C. To do this, we have only to look what angle is formed by C with the base, or in other words see how many degrees the angle is from C to B. Accordingly, we set the vernier of our semicircular protractor* to 126° 45′, namely, the angle C A B; and then place it so that its centre shall be at the point A, while its diameter agrees with the base line A B. A line is then drawn along the arm of the protractor, which line will determine the direction of C, forming an angle, C A B, of 126° 45′. This done, we are prepared to lay down the directions of E and F. The angle from C to E is 65° 50′; set the protractor to that quantity, but its position requires to be changed, as its diameter must now agree with the line, A C, while its centre continues, as before, at A. A line is now drawn, forming the angle, C A E; and in the same manner the direction of F is obtained, forming an angle, C A F, of 96° 40′. Next, for G and H, lay off from A B 22° 25′ for G, and 80° 10′, for H. Adjust the protractor on A B, with its centre at B, and lay off 40° 20′, the angle A B E, and 100° 2′ for the angle, A B F; draw lines, B E and B F, which will intersect A E and A F, thus determining the points E and F. Afterwards, draw G B, making an angle of 64° with A B, and on G B, as a base, set off 31° 40′ for the angle G B H; G and H will then be fixed by intersections with the lines, A H and A G.

Observe, when at A, the reason for taking angles from C towards B was to avoid the inconvenience of reading angles backwards on the horizontal circle of the theodolite, which would have been the case had we taken the angles to F, E, and C from B. The angles might, however, have been taken from B to G, then to H, and continued

* See section on the protractor and plotting.

round to C, E, &c.; but the other way is most simple, and therefore easiest to be understood.

The angles taken at E are now to be protracted, together with those taken at C and F.

In the survey before us, we have E determined by observations from A and B. C, from A and E. F, from A, B, and E. D, from C, E, and F. The work then proceeds, taking the lines, A C, C D, D F, &c., as bases. Had it been desirable, we might have found the length of the line E H, and worked from it as a base of greater length, and, consequently, furnishing a foundation for larger triangles.

When a survey is of limited extent—say, from four to six square miles—I would suggest that the base be laid down on a small scale, and the angles protracted with the ivory protractor in the field. This is quickly done, and will be found an advantageous method by persons who have not much practice in surveying, and who are consequently liable to make mistakes when they come to plot from a field-book alone; but doing this is by no means to be understood as superseding the necessity of going over the whole protraction on a large scale, and more accurately, afterwards.

After what has been said in the early part of the work, when treating of military sketching with the compass, it may be almost superfluous to dwell here on the manner of filling in these triangles; however, I shall say a few words upon the subject. Before entering into any details, I ought to observe, that in extensive surveys what are called *secondary* triangles are always formed within the great triangles, so as to subdivide each of them into several, smaller ones, affording stations carefully determined, for intersecting the various objects contained within their limits. But in the kind of survey we have been con-

sidering, where the sides of the triangles are under a mile in length, this proceeding is not followed; and something like what I am about to describe would be the method to be pursued.

Referring to the little example in the plate, the course of the river would probably first engage our attention in the filling in; to obtain which, I should place marks, as a, b, c, d, &c., and intersect them from the ends of the base, or by taking angles or bearings from any of the points previously fixed on the plan. The mention of bearings reminds me that a meridian line has not yet been laid down; this is to be done while the theodolite stands at one end of the base, by observing how the other end bears, or by using any other fixed points for the purpose. For instance, we find that B bears from A 76° 10′ N.E. On the plan, then, it is only requisite to make the angle N A B, 76° 10′, and the line N S becomes the magnetic meridian.

To return to the filling-in of the survey; the points, f and k, the extremities of a little island, are fixed by angles from A, H, and E. To determine the situation of the bridge, take a bearing from A, and measure the distance. Do the same at B, to find the position of d. Observe, that an experienced surveyor takes the bearing of every object likely to be of use to him in filling in, at every station where the instrument may be set up; as a little foresight often saves him the trouble and loss of time occasioned by the necessity of returning to a station.

The roads, &c., are obtained by traversing, as described in Section VII., beginning at any convenient point fixed during the triangulation. The theodolite is then adjusted, and directed on some conspicuous object already determined; the line connecting which with the place of the

theodolite becomes a working meridian to which all the angles during the traversing are referred.

The skeleton of a survey having been carefully laid down to the required scale, and found correct, portions of it must then be transferred by tracing, to pieces of paper or pasteboard of a convenient size to use in the field with the sketching case; when the hills, and every required detail, are put in with the aid of a surveying compass; the method of using which instrument has been fully shown in the first four sections, and some additional hints upon sketching ground will be found further on.

During the progress of a survey, advantage should be taken of any portion of level ground over which it may be carried, to mark off a convenient distance, which should be measured in precisely the same manner as that by which the length of the original base was obtained; then, a comparison between the length of such line, as measured, with its length on the plan—found either by computation, or by applying it to the scale used for the survey—will be a test of the accuracy of the work. A line measured for this purpose is called a base of verification; and one or more, according to circumstances, should be made use of in all surveys.

Let me hope that enough has now been said to put the young military surveyor on a right track to acquire a knowledge of the art sufficient for military purposes. Ordinary surveying is a very simple process; but to perform that process well requires both attention and experience. I trust this book will be found to contain all the information on the subject that the young officer will require; and, should he be desirous of studying *trigonometrical* surveying, he may consult, "*Outline of the Method of conducting a Trigonometrical Survey,*" by

LIEUTENANT FROME, *Royal Engineers;* and *Practical Geodesy, &c.,*" by BUTLER WILLIAMS, Esq., C. E.

It may be as well to remark that the diagram (plate X.) is supposed to represent the commencement of a survey for military objects, of some four or five square miles, to be made with greater care than a mere military sketch, such as has been described in Section V. A survey of greater extent—say fifteen or twenty square miles—would require much larger triangles, and a very different arrangement.

SECTION X.

OF THE PROTRACTOR AND PLOTTING.

For laying down or protracting angles measured with a theodolite, or other instrument by which they are obtained to minutes, or less, of a degree, a superior kind of protractor becomes necessary; for, as we have already observed, it is of little avail that angles are taken to minutes, unless they can also be laid down on paper with corresponding accuracy. Accordingly, metal protractors of both circular and semicircular forms, and furnished with a vernier, are used.

In Volume I. of Papers on Subjects connected with the Duties of the Royal Engineers, is one on protractors, by S. B. Howlett, Esq., Chief Draftsman, Ordnance, which I shall quote at length, as it contains some just observations on them; his method of plotting also deserves to be generally known. He says:—

"The circular protractor, at the price of from four to eight guineas, is generally considered the most perfect kind of instrument for plotting the angles of a survey; but against this instrument there are the five following objections:—

"It is only steadied by being attached to the paper by pins; and in moving the arm it is liable to shift.

"As the vernier has to be set while the protractor is fixed on the paper, and cannot be held to the light, it is next to impossible, in some positions, to see the divisions; or, if the protractor be taken from the paper, time is lost

and error is caused by having to replace it on the working meridian.

"When the whole set of angles required are set off and numbered, they have to be transferred to the station, one after the other, with parallel rulers; in doing which much error creeps in, both while setting the edge of the ruler against the points, and then in shifting the ruler along to a distant part of the paper.

"It is a very delicate instrument, liable to be soon strained and rendered unfit for use.

"Lastly, the general inaccuracy of the method which this instrument implies—for the sources of error are so many that the work cannot be brought to close in a satisfactory manner—and when done, it is little better than a survey plotted by a common protractor, where the degrees and half degrees only are marked.

"The old surveyors of the Ordnance used the semicircular protractor, and transferred the instrument itself to the station, by means of large parallel rulers fixed on the paper; and having set the arm to the required angle, they drew the line against the arm itself, some inch or two of which was made in a line with the centre and zero. This excellent way was, however, rendered inaccurate by the impossibility of preventing the joints of the large three-bar parallel rulers from becoming loose; and much inconvenience was felt in consequence of the rulers, even at a great price, not extending sufficiently wide to carry the protractor over a small sheet of plotting cartridge-paper.

"These methods of plotting a survey to a small scale, where an error of ten minutes is not very striking, may answer, and escape censure; but in making surveys of several thousands of acres for content, to a large scale, I have found all the methods above described exceedingly awkward, and not at all adequate to the plotting of the

PLATE XI.

Fig. 1.

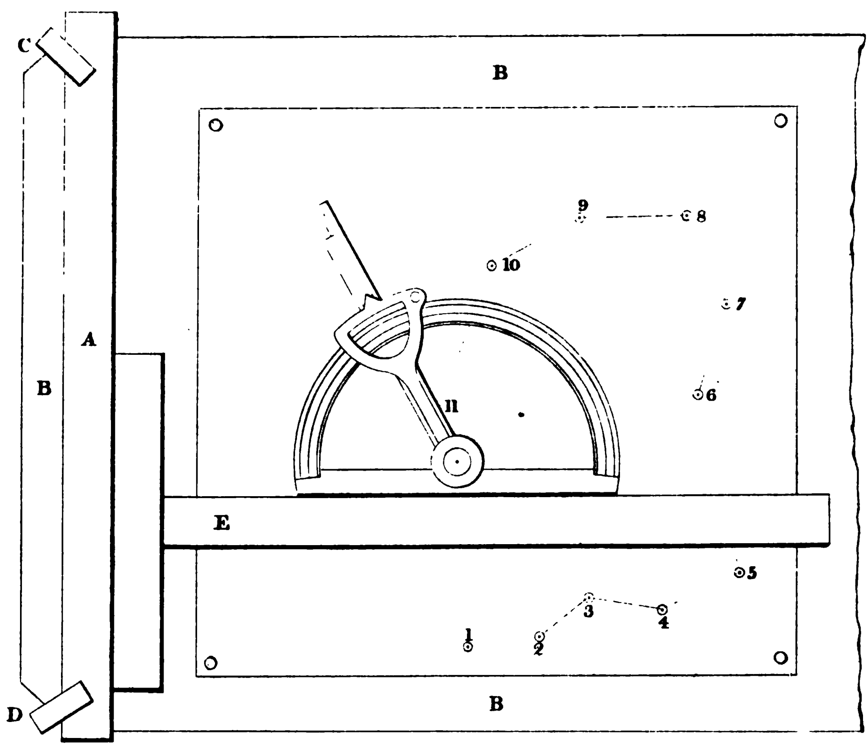
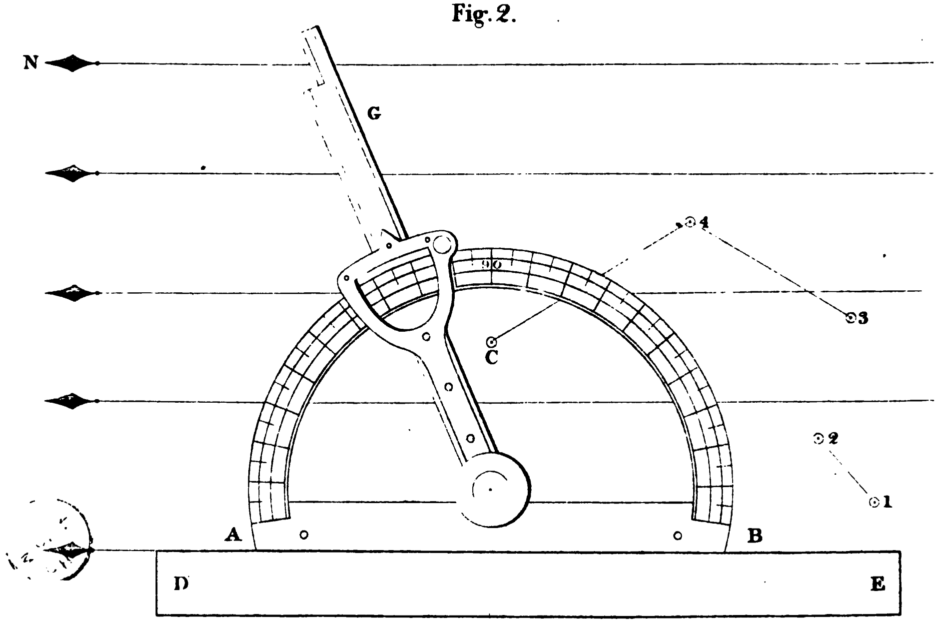


Fig. 2.



perfect work done by the theodolite. In making surveys of estates and parishes, while on half-pay, I suffered much for want of a better system of plotting than any I could find, after making every inquiry, and searching books on the subject. Such methods as these do not meet the exigences of practical men, and hence it is usual to employ the chain alone. The theodolite is very little used among private surveyors; they reject the system altogether; and, indeed, many use the chain so skilfully that, under ordinary circumstances, it leaves nothing better to be desired. The theodolite is, however, an invaluable instrument; and if the proper use of it, together with a more satisfactory method of plotting, were more generally known among private surveyors, much of this prejudice would certainly give way.

" Anxious to discharge the duty confided to me in the most beneficial manner, I have given much study to this as well as to other branches of my duty, and have the honour to submit, at least for trial and discussion, the following very cheap and simple means; which are, in all respects, the nearest approach to perfection that I can contrive:—

" The pattern semicircular protractor, at the price of no more than £2 17*s*., was contrived and made from my drawing and instructions, some few years ago, and must be too well known in the department to need description.

" As, when away from home, it seldom happens that the surveyor can obtain a good drawing-board, or even a table, with a good straight edge, I fix a flat ruler, A, to the table, B B B (plate XI. fig. 1), by means of a pair of clamps, C D, and against this ruler I work the pattern square, E, one side of which has the stock flush with the blade; or, if a straight-edged board be at hand, then the square may be turned over, and used against that edge

instead of the ruler, A. Here, then, is the most perfect kind of parallel ruler that art can produce, capable of carrying the protractor over the whole of a sheet of plotting paper of any size, and may be used upon a table of any form. It is convenient to suppose the north on the left hand, and the upper edge of the blade to represent the meridian of the station.

"This protractor is held in the hand while the vernier is set, which is an immense comfort to the sight; and it will be seen that, as both sides of the arm are parallel with the zero and centre, the angle may be drawn on the paper against either side, as the light or other circumstances may render desirable.

"From this description, and a mere glance at the plate, it is clear that angles taken with the theodolite can be transferred to the plot as accurately as the protractor can be set, namely, to a single minute; and that, too, in a rapid and pleasant manner.

"By means of the notch at the ènd of the arm, this instrument may be used in the manner of a circular protractor, should a square not be at hand.

"This protractor is specially for plotting a survey, and therefore is figured from left to right: but should it be required for other purposes, to set off an angle from right to left, then mark off the supplement of that angle."

The experience of practical men is always highly valuable, and we are indebted to Mr. Howlett for the above useful remarks. His method of carrying the protractor forward is excellent, and the instrument itself is a very good one; as I can vouch for, from long experience.

Notwithstanding the superiority of moving the protractor forward by means of a T ruler, I think military men will often be disposed to use the large three-bar parallel ruler on account of its portability. One bar is

fixed, either by means of leaden weights or small screws, while the others advance over the paper, pushing forward the protractor.

There is another method, which ought to find a place here, being still more suited to our wish, for portability, as it requires no ruler to work the instrument with. A number of parallel lines are ruled upon the paper at about an inch or so apart, to represent meridians, which are marked *north* and *south*. The semicircular protractor is then set to the required angle: a point is next marked on the paper for the first station, and the protractor is then adjusted to any convenient meridian so that the ruler part or base of the instrument may coincide with one of the meridian lines, while the bevilled or fiducial edge of the arm cuts the station-point: a line has then to be drawn along the edge of the arm through the station-point, and the bearing is laid down. A common flat ruler is, however, useful in this method of protracting. Lay the ruler along any convenient meridian; and, having set the protractor to the required angle, place its base, A B, along the edge of the ruler, D E (see fig. 2, plate XI.), so that the arm, G, may not touch the station, C: the ruler, D E, is then kept steady, while the protractor is gently pushed along until the edge of the arm agrees with the station-point, C.

SECTION XI.

ON PLAN-DRAWING—METHODS OF SHADING HILLS, ETC.

We have seen, in the foregoing sections, the manner of proceeding in the field, in order to obtain the necessary measurements of a survey. It has also been shown how those measurements are laid down on paper, or plotted, so as to furnish a rough skeleton plan of the work. I shall now speak of plan-drawing, in its more limited sense, or the method of expressing upon paper, according to certain conventional rules, the various objects which the face of a country presents, and that are required to be delineated by the topographical draftsman: but of these, the drawing of hills alone demands serious attention, for all the rest give us no difficulty whatever.

Objects having elevation can only be expressed upon a flat surface, such as paper, by means of shade, or by being thrown, as it is called, into *relief;* and consequently we can only give this appearance of *relief,* or being raised above the surface of our paper, in a ground plan, to bodies whose forms present either slopes or curves; unless we depart from the principles that govern a ground plan, and give an elevation to such bodies, in the manner seen on very old maps and plans: a practice which has universally been discontinued, since the introduction of the present system of plan-drawing.

A hill, therefore, presenting slopes, can, according to our conventional system of shade, be faithfully expressed on a ground plan, so as to convey an idea of elevation to all

who are acquainted with the principles of plan-drawing; but we are unable to give the appearance of elevation to a building, because its walls are perpendicular. In reality, this is a matter of no consequence whatever, for the mind at once connects the idea of height with castles, churches, houses, &c., and our method of shading hills enables us, at the utmost, only to form a loose judgment of their height as compared to each other, for we cannot determine by it the actual elevation of any single hill. But for ordinary military purposes, an approximation to their *comparative* height is generally sufficient; and when, for any particular object, it becomes necessary to determine the actual elevation of any point above the sea, a river, &c., we can ascertain it either by *levelling,* or by a problem in the application of trigonometry to the measurement of heights; and likewise, but with less accuracy, by means of the mountain barometer.

The theory most generally adopted, supposes the light to fall vertically upon the hills, in parallel rays; according to which steep slopes, receiving those rays at a more oblique angle than more gentle ones do, are therefore illuminated in a less degree, than the latter, and must be shown in a plan by a darker shade; while such portions of the ground as are horizontal, and receive, consequently, the rays of light perpendicularly to their planes, being thus illuminated in the greatest degree, are left without shade in a plan; but, as it is scarcely possible to fix a criterion for the depths of tint in shading to express ground, it is idle to suppose that, *practically,* the shading can ever be so exact as to enable us to measure by it the positive height of a hill.

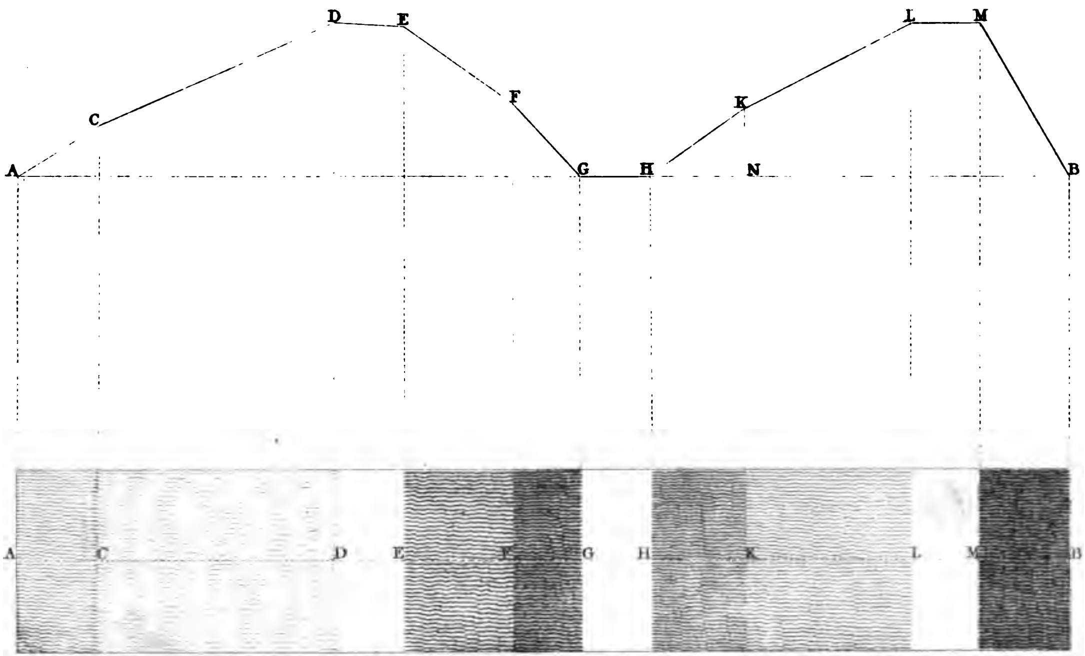
I fear it is almost impossible, by means of plans and descriptions, to convey at once to the mind of a student a clear perception of our *conventional* system of expressing

hills upon a plan; yet, if he will only have the patience to labour a little for himself, I think he may contrive to make it out. In the first place, he has to bear in mind that all distances shown upon a plan are horizontal ones; for instance, referring to plate XII., the line, H K, of the section, which is the hypothenuse of the right-angled triangle, H K N, is represented on the *ground plan* below by the line, H K, which is equal to H N in the section; and in the same way, M B, a precipitous fall in the section, only occupies the space from M to B on the ground plan. Thus it is seen that the height of mountains or the depression of valleys exercises no influence upon the situations of objects in a plan. I may mention here that the level of the sea is, in great surveying operations, considered as the horizontal plane, to which all measurements must be reduced.

But as regards the expression of hills on a plan; suppose we are standing on one of a perfectly conical form, it is obvious that rain falling on its summit will trickle down towards the base in minute, diverging streams;—our vertical style of shading hills has been likened to these. The immediate purpose, however, of plate XII. is to show the principle upon which slopes are expressed by means of shade: this is made light or dark according as they are gentle or steep. The section given represents ground of varied character; A is on a level with the sea; from that point the hill has a steep rise to C, from whence it is somewhat more gentle as far as D; at E a descent begins, and continues to F, from whence there is a steep slope to G, and so on. I have endeavoured to make the shading of the ground plan to agree with the section: for instance, that from C to A is darker than between D and C. From D to E the ground is level, and therefore no shade appears. The slope from E to F, being greater that from D to C, is

Plate XII.

Section on A.B.



Ground Plan

shaded darker; F G, being steeper, is made darker still, and the deep shade from M to B is equal to the shading of both of the slopes L K and K H.

I shall not fatigue my reader with any further description: he must now try and make out the corresponding parts of the ground-plan and section for himself. But perhaps he may stumble at the threshold, not knowing what a section is; the term profile would have been better, for that means a *vertical* section. It may serve to convey an idea of a profile of a hill, if the reader will call to mind the appearance it would present in hazy weather, when nothing but the outline is visible; or, referring to the ground plan in plate XII., let him conceive the ground there represented to be cut away from the dotted line A B, so as to leave the face of the remaining part of the ground perpendicular: this face would then present the exact appearance of the profile given in the plate.

By a little attention to what has been said above, I think the student will be able to comprehend the nature of a ground plan of hill features, with its corresponding section, as here shown.

METHODS OF SHADING HILLS, ETC.

The shading of hills may be performed by using a black-lead pencil, with a pen, by washes of Indian ink or neutral tint, &c.

There are two modes of expressing inclinations of ground with the pen or lead pencil, distinguished as the vertical and horizontal manners. In this country, opinion is divided as to which method is the best for general purposes. The vertical mode, as already stated, assumes the pen strokes to represent such minute rills as water forms when trickling down the slope of a hill. The *horizontal* manner marks the contours of hills by waving lines, each line

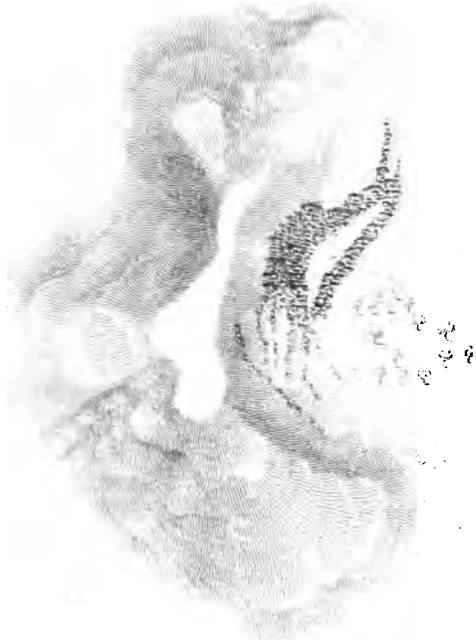
continuing on the same *level* while following every undulation of the ground; as, in some hilly parts of this country, sheep paths may be observed, often covering the entire faces of steep declivities, at a few feet apart, and horizontally pursuing their windings. Plate XIII. shows the same hill, drawn in both the horizontal and vertical styles.

Mr. Burr, the Professor of Military Surveying at Sandhurst, showed me some years since what I think a very ingenious and striking way of conveying a just idea of this style, by means of a model in plaster of Paris, representing some hilly ground. He had enclosed his model in a wooden box, which was then filled with water. A scale, divided into quarters of an inch, having been placed upright in the box, the water was allowed to run off through a hole near the bottom, by a quarter of an inch at a time, as indicated by his scale. At every successive fall of the water, he traced lines on the model, indicating the curves shown upon its surface by the successive lowering of the water. When the operation was completed, the surface of his model exhibited a number of lines, all of course perfectly horizontal; closing upon each other where the hills were steep, and diverging again where the slopes became more gentle. A model so prepared is easily represented on paper, and with great accuracy; and I cannot do better than recommend those who are desirous to obtain a thorough knowledge of *ground*, to consider the horizontal method with attention, as it reduces the delineation of hills to something of a fixed principle. In practice, either or both of the styles may be used at the pleasure of the draftsman, or as may be best suited to the nature of the ground he wishes to pourtray. The sketch in plate V. is a specimen of the horizontal manner of shading.

The vertical style of sketching hills used to be generally practised in the British service; so much so, that I do not

PLATE XIII.

Horizontal Style



Vertical Style

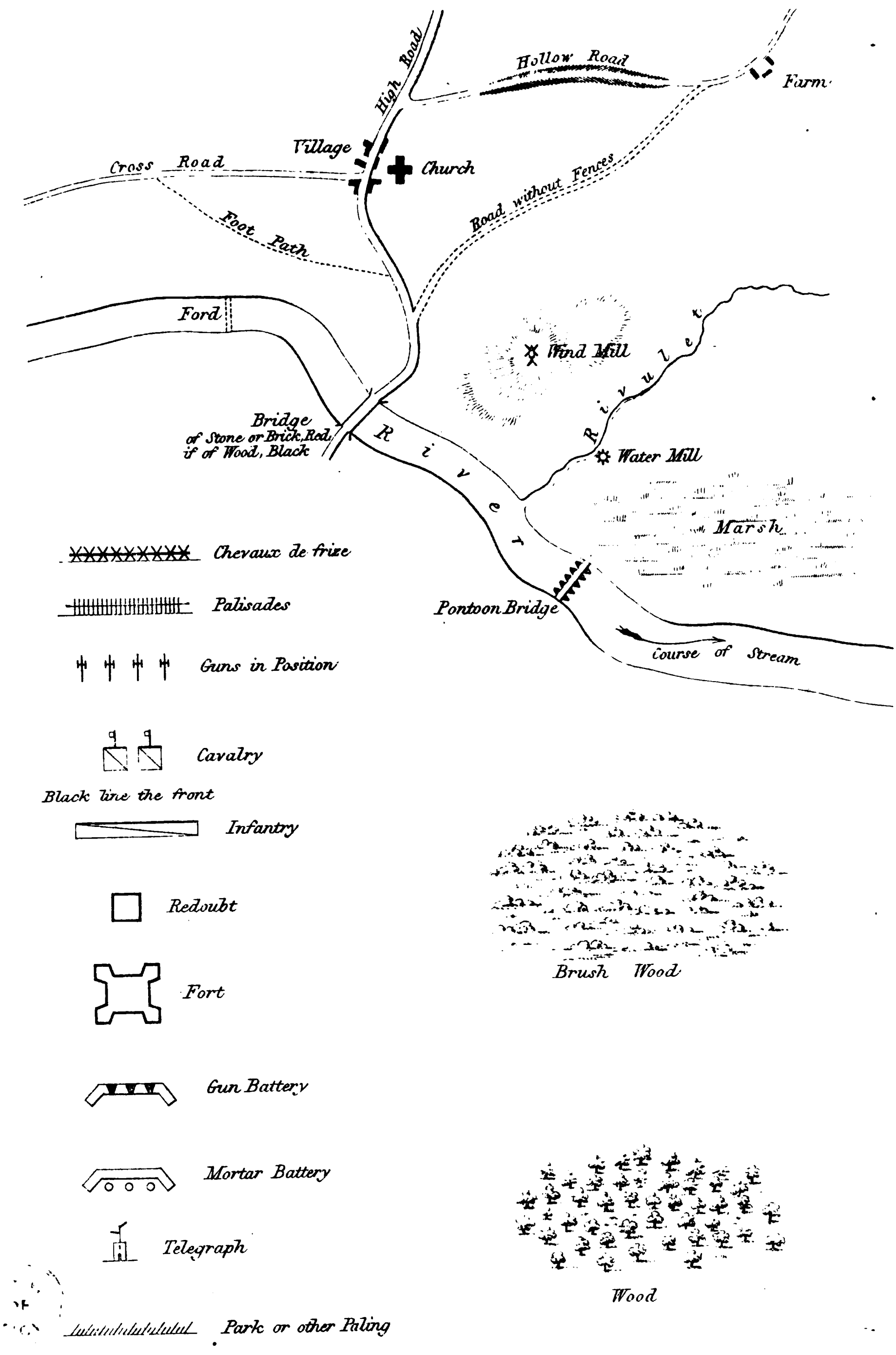
think a single officer of the Royal Staff Corps employed the horizontal manner; but, of late years, the latter has been in favour at our military colleges, and now bids fair entirely to supersede the vertical method.

If the student could procure a good model or two, with plans of them, he would derive great advantage from an attentive comparison of the latter with the former. He might then lay aside the plans and endeavour to make others for himself from the models, which he could afterwards compare with the other plans. By such a practice, he would speedily attain to great facility in sketching, and the knowledge of ground: after which he might proceed to sketch from nature, which he would find very easy, owing to his previous course with models. Unfortunately, good models and plans of them are not easily procured; the student must, therefore, go at once to the field, and work from nature, as shown in a former section, on Sketching Ground.

The most rapid way of expressing hills upon paper, is by shading with Indian ink or neutral tint: for this, two camel-hair brushes are used, one to lay on the tint with, and the other for softening it down. A dexterous hand will, in this manner, speedily dash in the hills of a plan; but a few touches with a pen over the shading, enable an artist to give form to the features of ground with less labour than by brush-shading alone. All touches, however, that are introduced with no other object than to produce effect, are very objectionable. If rugged ground is to be pourtrayed, free touches become necessary; but the judicious draftsman will endeavour to suit his style to the nature of the hills he has to express: steep and broken declivities will admit of freedom in the touch, but smooth and gentle slopes must be made to preserve their proper

character; and yet a proficient with the brush or pen will always contrive to throw a certain degree of spirit into his performance, whatever may be the nature of the ground he is representing: but this is the result of much practice, combined with a natural taste for drawing.

I have already said that the rays of light are supposed to fall vertically upon the ground, and that the degree of shade used for expressing hills depends on the greater or less gradations of their declivities; that is, the more the slope of a hill recedes from the horizontal, the darker must be the shade. Now, although I consider this principle as generally the best, yet, in making a finished plan of any mountainous region, I would not confine an artist too rigorously in this respect; for a clever draftsman would then like to throw his mountains into what we term light and shade, which supposes the rays of light to come on the plan from the left upper corner; according to which supposition, one side of a hill becomes brilliantly illuminated, while its reverse is cast into deep shadow. I have seen some very beautiful specimens of plans executed in this manner, by which a surprising effect was produced. Attempts have been made to have the oblique-light system generally adopted, but it is not suited to express tame ground. A kind of compromise therefore subsists; thus, we make the rays of light to fall vertically upon the hills, while all other objects, as rivers, houses, trees, &c., receive it obliquely. This, to be sure, does seem rather absurd; but, where all is conventional, the contradiction is not felt as an inconvenience; and it may be observed that, generally speaking, the object of giving shadow to houses, rivers, &c., is chiefly as a finish, and for effect; although, in the plans of engineers and architects, it is usually attended with utility.


High Road
Hollow Road
Farm
Village
Church
Cross Road
Foot Path
Road without Fences
Ford
Wind Mill
Rivulet
Bridge
of Stone or Brick, Red,
if of Wood, Black
River
Water Mill
Marsh
Pontoon Bridge
Course of Stream
Chevaux de frize
Palisades
Guns in Position
Cavalry
Black line the front
Infantry
Redoubt
Fort
Gun Battery
Mortar Battery
Telegraph
Park or other Paling
Brush Wood
Wood

Little need be added with respect to mere plan-drawing: since it is, in its most limited sense, so intimately connected with field sketching, that strictly speaking they can scarcely be separated: besides, I do not think it would be attended with any advantage to the student, were I to enter minutely into the details of plan-drawing. From description alone, I conceive it to be out of the question that any one can form a correct idea of the manner of executing a finished plan; neither do I consider very great skill in the art as imperative on officers in general. All that is really wanted for use in the field may be scratched with a pen. A person seeking to acquire a thorough knowledge of military plan-drawing, must either procure plans to copy, or obtain instruction in the art beyond what a book can furnish; I therefore hold it useless to swell my pages with elaborate details on the subject.

Plans are copied in various ways. The best is by tracing at a glass frame or window: for which purpose the paper intended to receive the copy is pinned to the original. When mounted on pasteboard, or other opaque substance, some other mode must be resorted to, as that of dividing the original plan into compartments or squares, by ruling lines upon it lightly with a pencil; similar squares are then formed on the paper, and the copying becomes easy. This latter method is employed for increasing or diminishing the size of the copy, as compared with the original. By using what is called tracing paper, through which the details of a plan are visible, a copy is speedily and very correctly made; and afterwards, if necessary, a tracing may be made from it upon thick paper at a window. There are also other methods, but the above are sufficient.

Plate XIV. contains the conventional signs in plan-drawing which are generally employed: instead of multiplying

these to an inconvenient extent, it is better to make memoranda on the plans. For instance, signs are sometimes used to denote whether a ford or a marsh be passable for troops; and even to notice whether practicable for infantry, as well as guns and cavalry; but, in my opinion, it is better to write, in language that cannot be mistaken, what description of ford it may be.

SECTION XII.

HINTS ON SURVEYING, PLAN-DRAWING, AND SKETCHING.—THE CLINOMETER.—SKETCHING WITHOUT INSTRUMENTS.

MILITARY TOPOGRAPHY, notwithstanding the boasted improvements made in it abroad, together with some attempts to advance the art amongst ourselves, is, so far as I may pretend to give an opinion, nearly where it stood thirty or forty years ago. And the same remark holds good with respect to surveying generally: this, however, is by no means surprising; surveying, in all its branches, being an exceedingly simple process, requiring, it is true, for great trigonometrical operations that the surveyors should be men of science, in order that certain measurements may be made with the utmost possible accuracy; yet the principles of surveying are easy of acquirement, and their application, under ordinary circumstances, requires little beyond good instruments, and great exactness in the use of them. Few persons can rise from a study of the Account of the Trigonometrical Survey of the United Kingdom, without entertaining an impression that geometrical and trigonometrical operations, as applied to measurement on the earth's surface, have been carried very nearly to perfection.

So far, then, as horizontal measurements are required, whether for the purpose of mapping countries, or of determining the length of an arc of a meridian, it does not seem that anything remains to be desired.

Again, the height and exact slopes of hills, as also the depression of valleys, to suit the purposes of the military or civil engineer, can be obtained with the utmost accuracy, by means of levelling and trigonometrical operations. So that in every accessible part of a country, the most perfect knowledge of its surface, whether flat or mountainous, may be obtained: and, having plans and sections accurately drawn to a scale, we can at any time measure distances upon paper. But although we can measure *horizontal* distances over every part of a map or plan, yet *vertical* measurements, as those of heights and depths—shown on paper by *sections*—can only be made upon the precise lines along which such sections have been carefully taken; and if other vertical measurements are wanted, our ground plans can avail us nothing: we must proceed to the ground, and ascertain them by actual operations.

Herein lies the imperfection of plans; and the attention of scientific men has long been directed towards the discovery of a method of drawing ground plans, from which sectional measurements may be made. Hitherto their efforts have been attended only with partial success; that is to say, by means of very great accuracy in taking measurements over the surface of a hill—similar indeed to what would be requisite for sections: a knowledge of its form being obtained, symbols are used to designate a certain degree of perpendicular elevation, together with the angle at which the hill slopes at each gradation. Thus, in France, military engineers run a succession of horizontal lines round their hills at every ten mètres of difference of level, by which they obtain two sides (with their included angle) of a right-angled triangle, namely, the perpendicular height of ten mètres, and the *base* of the slope, for that distance of perpendicular height, with the included right

angle; from which data the value of the slopes at every gradation can be obtained.

In some of the continental countries a system of shading is used according to a scale; different degrees of shade representing the angles at which a hill slopes. This is the principle of Major Lehman's method, and prevails to a certain extent among the Germans.

A few years ago, the late Sir J. C. Smyth, of the Royal Engineers, published a little work, to recommend a modification of the *normal* system, as set forth by Colonel Van Gorkum, of the Netherlands' army, for adoption in our service. But I very much doubt whether any of these systems can be rendered available for general topographical purposes.

The system of tracing contour lines, upon a plan of any portion of ground, as introduced by the French officers of engineers, is now gaining ground amongst those in the British service, and is practised in the trigonometrical survey under the direction of Colonel Colby; "these lines being traced at short, *known, and generally equal vertical distances* over the ground, afford ample data for the construction of sections in any required directions, and even for a model of the features of the ground."* The method of tracing such contour lines will be found under the head of *Levelling:* the process is necessarily slow; but there can be no question, that a plan of any portion of ground may thereby be obtained with almost mathematical accuracy. A moment's consideration will, however, convince any one that it is wholly unsuited to the ordinary purposes of the topographical draftsman, who has often a considerable extent of country to sketch in a very short

* "Outline of the Method of conducting a Trigonometrical Survey," &c., by Captain Frome, Royal Engineers.

time; and for objects, moreover, which do not require the ground to be delineated with extreme precision.

Most assuredly it is a great desideratum, to be able, by the inspection of a map or plan, to determine the elevation of the hills; and the person who may discover a truly practical system, that shall be at the same time general in its application, will confer an immense benefit on the art of plan-drawing. At the same time, however, the student must be cautioned against acquiring erroneous notions on this subject; such a discovery, though unquestionably of great importance, as at once rendering a plan perfect, would not, in my humble opinion, add so much as might be imagined to its utility for the general purposes of war. It appears to me that, looking exclusively to these, the height of hills, as compared with others near them, is the principal consideration with a General. Next to which, in point of importance, comes the nature of the slopes; whether steep and rugged, or gentle and smooth; how far practicable for his troops of all arms to operate upon. But whether the summit of a hill, or of any portion of ground, be a certain number of feet, more or less, higher than the sea, or than the level of a river flowing near it, can be of no moment whatever.

A practice formerly prevailed, and one that might probably be revived with advantage, by which the comparative heights of hills were at once seen on a plan; I allude to their designation by numbers. This practice fell into disuse owing to the pretension it had, of not only serving to distinguish comparative, but likewise to show positive, elevation. For this latter purpose, a perpendicular height of 36 feet was termed a *command*, and the figures 1, 2, 3, &c., denoted so many of these commands. Like most of the attempts made to show positive vertical height upon a ground plan, this method by commands proved a failure,

from the impossibility of obtaining the data on which to lay them down, without a tedious levelling process. But, perhaps, we did wrong to reject the whole of the system, because one part of it was found defective; and in this opinion I would recommend a modification of it: thus, let the figures be reversed, and instead of giving the highest number to the loftiest ground in a plan, mark that as No. 1, the next in height as No. 2, and so on; giving, of course, the same number to ground of equal elevation. Our plan-drawers will here be ready to exclaim, " Oh, but this is all shown by the degees of shade, and there is no necessity for disfiguring our plans by numbering the features of ground in this manner." To which we may reply by an expression of doubt upon that point, seeing that all men who pretend to be draftsmen are not equally competent to produce plans that are to be depended on; what is termed a good knowledge of ground not being within the reach of every one, any more than is the *coup-d'œil militaire*. But, although we may often have doubts with respect to the correctness of the shading, we might be disposed to give some credit to the figures; for any one accustomed to sketching can always see whether a feature is higher or lower than another, when the difference is of any consequence; and on occasions where he may be unable to distinguish the higher ground, from the difference of level being slight, the same number may be used for both: besides, a plan so marked would be much easier read, particularly by persons not intimately conversant with the rules of plan-drawing.

The uncertain application of conventional rules, such as those which regulate plan-drawing, does a vast deal of mischief; and there is great reason to regret that such diversity of style in drawing should be tolerated in this country; but I fear there is no remedy for the evil. Could

we by any possibility be tied down to one approved style of delineating ground, such a measure would go far towards establishing conformity in the depth and gradation of shade among draftsmen. The ingenious author of " A Treatise on Practical Surveying and Topographical Plan-drawing, " Mr. Burr, has bestowed much care on the subject of shading plans, but few will be found to attend to his instructions. Yet, while the variety of styles complained of is suffered to exist, there can be no uniformity in this respect; the result of which is that, supposing two persons to have the same range of ground to draw, one of them will use shades twice as dark as the other. Thus, when an extensive district is to be sketched, upon which several individuals are required to be employed, it becomes impossible to unite their sketches, so as to form a complete whole; not can it be determined whose portion contains the most elevated ground.

This difficulty was not felt when part of the French territory was sketched by the officers of the Royal Staff Corps, after the Waterloo campaign. On that occasion the several sketches united very well, with one or two exceptions; as almost all the individuals employed were educated at the Royal Military College, and had, as I may say, a common scale of shades in their minds, and they had, therefore, only to agree upon the *style* to be used. It may be remarked that, almost universally, the shades used by draftsmen are too dark; they would do well to pay more attention to truth in their plans, and less to effect.

I would now suggest a few general hints to the military surveyor. He must have a triangulation, if possible, to establish certain landmarks, as the primary stations may be termed; after which the filling in of an extensive survey is done by laying down the roads, rivers, boundaries of woods, &c., so as to form a skeleton preparatory to sketch-

ing the ground. This effected, the suryeyor then examines the ridges, observes the sweep of a hill, or the direction of a valley, and refers all to the points already laid down on his paper. He takes few measurements, save by the eye, but finds his place by interpolation (Section IV.), as occasion may require. He commences at the highest situations, and, working his way downwards, is careful only to sketch the features he actually goes upon; as nothing can be more fallacious than to imagine the nature and slopes of any portion of ground not immediately under the eye. Every feature must be traversed if he wishes to ensure accuracy, and I recommend him to touch the hills in lightly at first, until he is quite sure of being correct; occasionally, also, he should hold his sketch so as to correspond with the ground, which is easily done by means of the fixed points, and observe whether the features on the paper agree with those of the country before him. He must be sure to take the bearings of all remarkable objects while at any situation that has been determined, as a little foresight may save the trouble of a return to it.

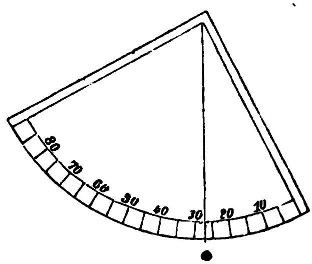
There is still a consideration that must claim the notice of the student, and which he must exercise his judgment upon in the field; namely, the degree of detail which his *scale* will admit of in sketching hills: thus a number of minor features which a large scale, as 20 inches to a mile, will enable him to express, must necessarily be omitted when the scale is only four or six inches to a mile. Indeed, this consideration should be attended to in all kinds of drawing, otherwise a mere mass of confusion must be the consequence. Again, if the scale be small, some objects require to be drawn larger than the truth; roads, rivers, houses, and indeed almost every thing introduced, must partake of this exaggeration, except hills; these can never be increased or diminished beyond the truth, but their

minor features may be expressed or omitted, according to the scale used.

Previously to taking leave of the subjects touched on in these few observations, I may observe that the most useful sketches are those which are rapidly made of country, in advance of an army in the field, termed reconnoitring ones; which is, in fact, exploring it. Under this head come, also, the necessary reports and sketches of roads, forms of which will be found further on, under the head of *Reconnoissance*. It may be some consolation for officers who have not had a regular military education at any of our colleges, to be told that this, the most important duty of a staff officer in the Quarter-Master General's department, does not demand by any means a perfect knowledge of military surveying. General intelligence, knowledge of languages, boldness, perseverance, a quick eye, and a prismatic compass, are his chief requisites: these have laid the foundation of many a one's military fortune.

I shall close this section with a few useful hints on sketching, by Captain Frome, Royal Engineers:*—

"The inclination of such slopes as are of peculiar moment should be measured with a 'clinometer,' and the angles written either on the slopes themselves or as references. This little instrument can be made by cutting a small quadrant out of paste-board, and roughly graduating the arc. A small shot, suspended by a piece of silk, forms the plummet; and, independently of its use in measuring vertical angles, it is of great assistance in tra-



* "Outline of the Method of conducting a Trigonometrical Survey for the Formation of Topographical Plans."

cing level lines in sketching the contours. The instrument sold under this name is made with a spirit level; but the substitute, as described above, answers the purpose equally well; and, moreover, from its being made merely of pasteboard, fits into the pocket of the sketching portfolio.*

"The slopes most necessary to note on a military sketch, are those which relate to the facilities of ascent for cavalry and infantry. According to the 'Aide Mémoire,' a slope of about

60°, or of 4 to 7, is inaccessible for infantry.
45°, or of 1 to 1, difficult.
If 30°, about 7 to 4, inaccessible for cavalry.
15°, —— 4 to 1, inaccessible for wheel carriages.
5°, ——12 to 1, easy for carriages.

"The leading features of ground are the summit ridges of hills (sometimes termed the watershed lines, and the lowest parts of the valleys, down which the rain finds its way to the nearest rivers and pools, called watercourse lines. These two directing lines, if traced with care, will alone give some idea of the surface of the country, and assist materially in sketching the hills; particularly if drawn on the horizontal system, as the *contour lines always cut the ridges, and all lines of greatest inclination, at right angles.* It is a very common error, on first beginning to sketch ground, to regard hills as isolated features, as they often appear to the eye; observation, and a knowledge of the outlines of geology, inevitably produce more enlarged ideas respecting their combinations; and analogy soon

* Captain Skyring, of the Royal Engineers, has devised a very convenient pasteboard clinometer, on the back of which are tables of natural sines and tangents. By means of this simple little instrument, we can obtain a close approximation, 1st, to the inclination of a slope; 2ndly, to the heights of a hill; 3rdly, the height of a column or wall; 4thly, to find the breadth of a river.

This little instrument merits the notice of military men: it is sold, with an explanatory paper containing diagrams, for a trifling sum, by Messrs. Elliott and Sons, 56, Strand.

points out where to expect the existence of fords, springs, defiles, and other important features incidental to peculiar formation; and appearances that at one time presented nothing but confusion and irregularity, will, as the eye becomes more experienced, be recognised as the results of general and known laws of nature.

"The representation of the outline of hills, and their relative command, is also materially assisted in a topographical plan, and *more particularly in a military reconnaissance,* by a few outline sketches taken from spots where the best general views can be obtained. A series of these topographical sketches, running along the length of a range of hills, and a few taken perpendicular to this direction, supply in some degree the place of longitudinal and transverse sections; and give, in addition to the information communicated by a mere section, a general idea of the nature of the surrounding country.

"A good judgment of distances is indispensable in sketching ground, even in filling up the interior of a survey; and more particularly in a reconnaissance, when there has not been either time or means for accurate measurement or triangulation. Practising for a few days will enable an officer to estimate, with tolerable accuracy, the length and average quickness of his ordinary pace, as also that of his horse—as on a rapid reconnaissance he must necessarily be mounted; and the habit of guessing distances, which can afterwards be verified, will tend to correct his eye. A micrometrical scale* in the eye-piece of his field telescope, with a corresponding table of distances, is also a very useful auxiliary; and the gradual blending of colours, the angles subtended at different distances by objects of known dimensions, such as the height of a door or a man, and the well-known rate at which sound has

* See description of Dr. Brewster's micrometrical telescope, in vol. ii. of "Dr. Pearson's Practical Astronomy."

been ascertained to travel,* will also materially assist him. According to the 'Aide Mémoire,' the windows of a large house can generally be counted at the distance of three miles; men and horses can just be perceived, as points, at about 2200 yards; a horse is clearly distinguished at 1300 yards; the movements of a man at 850 yards; a man's head clearly visible at 400 yards, and partially so between that distance and 700 yards.

SKETCHING WITHOUT INSTRUMENTS.

In the first edition of this work no mention having been made of any system of sketching without the aid of instruments, the deficiency was pointed out to me by an officer of great experience in the Quarter-Master General's Department, during the Peninsular war, and who was many years in command of the Royal Staff Corps.† He remarked:—"There may, however, be occasions, when military sketches are hastily called for, that officers may find themselves, at the moment, unprovided with instruments. In such cases it is a great advantage to them if they have been accustomed to sketch by the eye, according to the principles and rules taught by the late General Jarry,‡ and laid down in full detail in his lecture on military sketching.

* "About 1140 feet in one second. A light breeze will increase or diminish this quantity fifteen or twenty feet in a second, according as its direction is to or from the observer; in a gale a considerable difference will arise from the effects of the wind. A common watch generally beats five times in one second." See 'Philosophical Transactions,' 1823.) The number of pulsations of a man in health is about seventy-five per minute: either of these expedients will serve as a sort of substitute for a seconds watch. The velocity of sound is affected by the state of the atmosphere indicated by the thermometer, hygrometer, and barometer; according to Mr. Goldingham, 1-10th of an inch rise in the barometer diminishes the velocity about nine feet per second.

† Lieutenant General Earl Cathcart, K.C.B.

‡ General Jarry was a talented Frenchman, who, many years since, instructed the students at the senior department of the Royal Military College, in military surveying, reconnoissance, &c.

"With the aid of a few points taken from a map of the country, if any such exists, or a knowledge of the distances between two or three places, which come within the compass of the sketch, sketches may be obtained, which, although at best much more imperfect than those more regularly surveyed, yet, if done with care and attention, are often quite sufficient for military purposes, and should, I think, receive a fuller notice when you publish a second edition."

In conformity with the opinion of such high authority, the following hints on sketching without instruments have been introduced :—

If no general map exists of a country in which military operations are carried on, it becomes necessary to construct one; and when great accuracy is not sought — which, indeed, may generally be dispensed with—this may be done with much rapidity, by combining the labours of a few staff-officers of experience in military surveying. The preceding pages point out the methods of obtaining maps and plans with the aid of surveying instruments; my purpose, at present, is to show how a loose kind of map may be formed without them, which, though confessedly incorrect, will yet be accurate enough for military objects.

I shall begin by entering a protest against all the methods that have come under my notice for prosecuting angular surveying by means of any *succedaneum* for proper instruments. Some years ago an officer of the French Engineers published a pamphlet to explain a mode of measuring angles approximately, by holding a common black-lead pencil at arm's length: I have tried this and other crotchets for obtaining the value of angles, and although it may be possible to come at an approximation by such devices, I must maintain that we can make better plans without

them; and, moreover, I hold them all to be inferior to the simple method of measuring an angle on the ground with a view to laying it down on paper. [See *Tracing Figures on the Ground*, &c.]

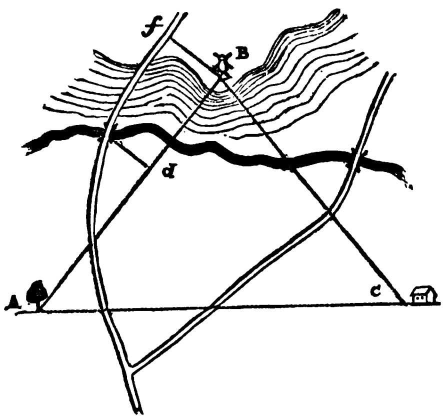
On the simple principle, derived from the properties of the triangle, by which a survey of great accuracy can be made with the land-chain, as explained and illustrated by a plan in Section XV., I assert that we may make excellent plans of military positions, and even construct district maps, without the aid of any kind of instruments, whether for angular or linear measurement. It is true that such maps, if of a considerable extent of country, could have little pretension to geometrical accuracy, but they would nevertheless, be fully adequate to every military purpose; while they would, at the same time, have the great advantage of being rapidly executed—a material consideration during active warfare.

The necessary measurements for reconnoissance, plans, and maps, may be made in four ways, according to the degree of accuracy required; these are,

1st. By pacing, using the marching step of thirty inches.
2ndly. By counting the paces of a horse, whose length of step has been accurately measured.
3rdly. By timing a horse when walking.
4thly. By obtaining the distances which separate towns, from the inhabitants of the country.

In a flat country the towns and villages are usually connected by roads running tolerably direct; and if the distances between any three, forming a triangle, are obtained by one of the above methods, the relative situations of those places can be laid down on paper, and the positions of other places may afterwards be determined

from any two of them as a base. In a mountainous district, however, it would not do to measure distances by keeping to the roads, as these generally take the most convenient, rather than the shortest, way of reaching any particular spot: so that two places may lie six miles apart, reckoning by the road between them, while geographically they may not be half that distance asunder.



To illustrate this method of sketching, let us suppose a tree, A, a windmill, B, and a house, C, forming a triangle, whose sides we can measure by pacing. Having laid down our triangle, we proceed to make our sketch, thus:—beginning at A, we find that at 500 paces towards B we cross a road leading to a bridge, of which we sketch the direction. Continuing along the line A B, we notice when we reach a point, *d*, where a line to the bridge would form a right angle with A B, ascertaining the point *d* by fronting the bridge and performing "right face." This fixes the bridge. Proceeding on towards B, we come to the rivulet, which is sketched as far as the bridge, and also in the opposite direction. We now mount the hill to B, and by measuring at right angles to *f*, we obtain the road from

the bridge upwards. After sketching the ground about B, we descend in the direction of C, and as we proceed sketching in the rivulet, bridge, and road; and then work in like manner towards A.

The system pursued by railway surveyors is eminently applicable to reconnoissance sketches, when the object is to delineate a belt of country; as, for instance, in front of the cantonments of an army, or along a line of road. Their practice is to mark out a straight line of considerable length, as a base; when the ground on each side of the base for a given distance—usually no more than six or eight chains—is divided into triangles, each of which is surveyed in succession, with the chain only. Wherever the projected line of railway diverges from the original direction, a new base line is marked out, and the angle which it forms with the preceding one is measured with a theodolite or other angular instrument. For surveying a narrow belt of country this method is a very good one.

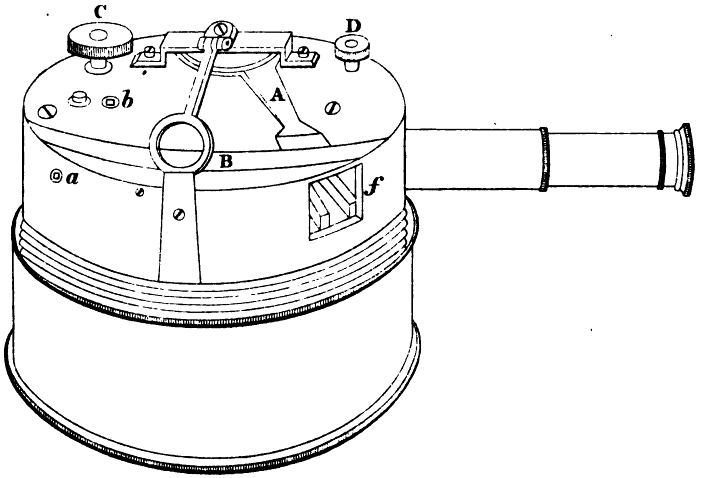
In European warfare it is rarely necessary to make a military map of great extent; but in every unsurveyed country it is highly desirable that an army should as speedily as possible furnish itself with itineraries of the principal routes, and a rough map of such parts as are likely to become the theatre of military operations. I believe that foreign officers in general pay more attention to such matters than is customary with us; and, *à propos* to this observation, when reading the account of Sir A. Burnes's "Voyage on the Indus to Lahore," I was struck with the industry displayed by M. Court, one of Runjeet Singh's French officers; I shall transcribe the passage relating to him:—

"Among these gentlemen, M. Court struck me as an acute and well-informed person; he is both a geographer and an antiquarian. M. Court, as well as his brother

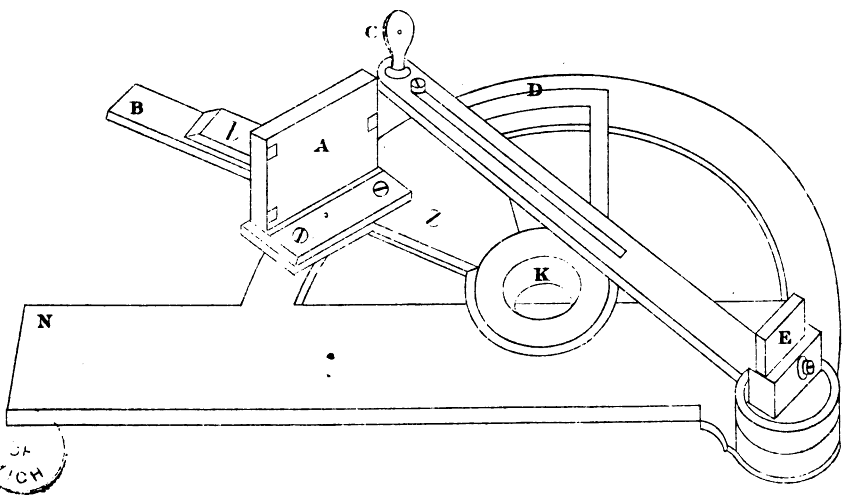
officers, was formerly in the service of one of the Persian princes, and travelled in India as a native, which gave him an opportunity of acquiring the best information regarding the intervening countries. He showed me the route from Kermenshah, by Herat, Candahar, Ghuzni, and Cabool, to Attock, constructed topographically with great care; and he informed me, at the same time, that he had been less anxious to obtain a complete map of that part of Asia, than to ascertain one good route, with its *détours*, and the military and statistical resources of the country. The French have much better information of these countries than ourselves; and M. Court, in explaining his map to me, pointed out the best routes for infantry and cavalry. This gentleman has likewise employed a residence of four years in the Punjaub to illustrate its geography; he has encountered jealousy from Runjeet Singh, but still managed to complete a broad belt of survey from Attock to the neighbourhood of our own frontier."*

* To show what may be done by intelligence and zeal, I shall here mention one or two surveying exploits which were performed in India many years ago by a native, who was servant to Major George Birch, now a retired Bengal officer, from whom he picked up a knowledge of surveying. That officer was with Sir David Ochterlony when hostilities against the Goorkhas were contemplated; and the native in question, Savaaje Khan, was sent into their mountains to reconnoitre, and endeavour to make a rough map of the anticipated scene of action. The man was absent six weeks, and returned with a most complete route-book, by means of which, and a base-line of the frontier that Major Birch had measured, a rough map was made out; upon which, combined with Savaaje's information, hostilities were afterwards commenced against the Goorkhas. A considerable time after the conquest of the country, the surveyor appointed by Government expressed his surprise at the accuracy of Savaaje's map. On a previous occasion, being desirous of information respecting parts where an European could not show himself, Sir David despatched Savaaje Khan, in the dress of a pilgrim, along the left bank of the Sutlej to Attock on the Indus, with directions to return by another route; the mission was satisfactorily performed; but the poor man nearly lost his life, owing to the detection of an instrument with which he had been supplied for taking angles.

PLATE XV.



THE BOX SEXTANT.



THE REFLECTING SEMICIRCLE.

SECTION XIII.

THE POCKET SEXTANT—ITS ADJUSTMENTS—USE IN SURVEYING, MEASURING HEIGHTS AND DISTANCES, ETC.—THE REFLECTING SEMICIRCLE—OPTICAL SQUARE—PLANE TABLE—RECONNOITRING PROTRACTOR—TO LAY DOWN A BEARING WITHOUT AN ANGULAR INSTRUMENT.

WITH a view of not distracting the attention of the student, little or no mention has been made thus far of any surveying instruments, save such as were absolutely necessary in order to illustrate our descriptions of the various methods of military surveying; but, although we have hitherto confined ourselves to the theodolite and compass, it is not to be inferred that we reject all others. The pocket sextant and the reflecting semicircle are both applicable to the purposes of military men, and may be advantageously used on many occasions instead of a theodolite or compass. I shall now proceed to give a particular description of the sextant, and to explain the several uses to which this beautiful instrument may be applied.

The pocket sextant combines numerous valuable properties; it measures an angle to one minute of a degree, requires no support but the hand, may be used on horseback, maintains its adjustment long, and is easily readjusted when put out of order. It enables us to determine latitude by a meridian altitude, and an approximation may even be made with it to the longitude, by means of lunar observations. Further, it is very portable, forming

when shut up a circular box under 3 inches in diameter, and only $1\frac{1}{8}$ inch deep.

The figure given in plate XV. represents the instrument screwed to its box, for convenience of holding in the hand, and with the telescope drawn out. A is the index arm, having a vernier adjusted to the graduated arc, B, which latter is numbered to 140°, but the sextant will not measure an angle greater than about 120°. The index is moved by the milled head, C, acting upon a rack and pinion in the interior. Two mirrors are placed inside: the large one, or index mirror, is fixed to and moves with the index; the other, called the horizon-glass, is only half silvered. The proper adjustment of the instrument depends on these glasses being parallel, when the index is at zero; while they are, at the same time, perpendicular to what is termed the plane of the instrument, represented by its upper surface or face. To observe whether the instrument is in perfect adjustment, remove the telescope by pulling it out, and supply its place with a slide for the purpose, in which is a small hole to look through; then place the index accurately at zero, and direct the instrument, holding it horizontally, towards the sharp angle of a building not less than half a mile distant, applying the eye so as to see both through the hole in the slide and also through the unsilvered part of the horizon-glass; the same object ought then to be so reflected from the index-mirror to the silvered part of the horizon-glass, as to seem but one with the object seen direct: if such be not the case, a correction becomes necessary, which is thus performed:—D is a key, removeable at pleasure, that fits two keyholes, the one at *a*, the other at *b*. Apply this key at *a*, and gently turn until the reflected object, and the one seen direct, seem but as one. The glasses are then parallel.

The next point is to examine whether the horizon-glass is perpendicular to the plane of the instrument. For this purpose hold the sextant horizontally, and look at the distant horizon; then, if any adjustment is wanted, two horizons will appear, and the reflected one will be higher or lower than the one seen direct; should this be the case, apply the key at *b*, so as to bring the two horizons together. Observe, that the large or index-mirror, being correct by construction, can want no alteration.

By looking at the sun, we can always satisfy ourselves with respect to the adjustments; the telescope has a dark glass at the eye end, and with this on we have only to place the index at zero, and, using the telescope, to look at the sun; when, provided the instrument is in exact adjustment, one perfect orb only will be seen. If the reflected image projects beyond the other, then correction is necessary. The full moon will answer as well as the sun for this purpose, but the dark glass at the eye end of the telescope must then be removed. The instrument is provided with two other dark glasses, which sink out of the way by raising two little levers at *f*.

It has been mentioned above that, for trying the adjustment of the sextant, an object must be half a mile off; this is on account of what is called the parallax of the instrument, occasioned by the necessity of placing the eye of the observer on one side of the index-mirror. Could we look from the middle of it, there would be no parallax; which is the angle subtended by the point of vision and centre of the index-glass, when observing any near object: consequently, as the distance of an object is increased, this angle diminishes, and at length becomes as nothing when compared with it. Half a mile is considered sufficient for all error to vanish, but at half that distance it is scarcely perceptible.

To take an angle, the observer looks either through the telescope or hole in the slide (having previously raised the levers of the dark glasses at *f*), at the *left*-hand object, holding the sextant horizontally in his left hand; with his right he turns the milled head, C, until the other object, reflected from the index-glass, appears upon the silvered part of the horizon-glass, exactly covering or agreeing with the left-hand object, seen direct through the unsilvered portion of the horizon-glass: the angle is then obtained by the vernier to one minute. Should circumstances render it desirable for the observer to look at the right-hand object, he has only to hold the instrument bottom upwards.

If the required angle be a vertical one, the sextant is held in a vertical position by the right hand, while the left turns the milled head, C, until the object is brought down to the horizon.

When the altitude of a celestial body is taken at sea, it is brought down, as the term is, to the natural horizon, and the measure of the angle, or height of the object, is read off upon the graduated arc; but on land the natural horizon can seldom be used, on account of its irregularity: recourse is then had to what is called an artificial horizon, such as a vessel containing water, mercury, or other fluid. The observer then places himself in a situation to see the reflected image of the sun or other body in the fluid; he has only then to bring down the image, as reflected from the index-glass, until it reaches its reflection in the fluid: the altitude will then be *half* the number of degrees indicated by the graduated arc, subject to certain corrections, not necessary to be explained here. [See *Artificial Horizon.*]

The chief, and indeed only objection to the sextant, as a surveying instrument, arises from the angles taken with it

not being always, like those measured by the theodolite and compass, *horizontal* ones. If the theodolite be set truly level, we can take angles all round upon its circle, no matter whether one object be high and another low, and these angles will be what are termed horizontal angles; so that, were we to take angles from object to object and complete the circle, the sum of all those angles ought to be 360 degrees, or the measure of a circle. But if the same angles were to be measured by a reflecting instrument, they would not produce precisely 360 degrees, unless taken upon a perfectly level plain; owing to this circumstance, that to take an angle by the sextant, the two objects having to be brought into contact, namely, the reflected one and that seen direct, it is necessary for the observer to hold his instrument, not strictly horizontal, but in the plane of the two objects, or in such a position as will enable him to form the contact; and therefore, if one point is elevated very much above the other, the sextant must be held at a corresponding inclination with the horizon. Angles so taken require a reduction, as it is termed, to horizontal ones; that is, to what those angles would have been, had the points subtending them been on a level with the eye of the observer, which is what is understood by the term horizontal. But, as we seldom use the sextant to lay down points for a trigonometrical survey of importance, it rarely occurs that the reduction is required; indeed, to effect it with accuracy is attended with considerable difficulty, as the angles of elevation and depression must be known—a matter of no easy attainment with the sextant. It is better to avoid, if possible, the necessity of making any reductions, by selecting stations neither much elevated nor depressed; and three or four degrees either way can never affect an angle, so as to be of much consequence in military sketching. By a little management, too, a correct

eye will enable us to select some spot directly under an elevated object, and at the same time nearly horizontal; such mark may then be taken instead of the object itself: or we may take the angle between each of the objects we are observing, and some other point situated far to the right of them, and the difference will be an approximation to the angle sought. In short, a person habituated to the use of the sextant will generally be prepared with some contrivance, to obviate the necessity of having recourse to the reduction of his angles; which is performed, when requisite, by a calculation in spherical trigonometry, the formula for which will be given in another place.

An addition has lately been made to the pocket box-sextant, for the purpose of taking altitudes and depressions: it consists of two small spirit-levels, fixed at the back of the horizon-glass at right angles to each other; so that, standing before the object, you look perpendicularly down through the plain sight, and, moving the index, bring the image of the object to appear with the levels, which must have their air-bubbles in the centre of their tubes. The reading of the instrument will then show the supplement of the zenith distance, and its complement to 90° will be the angle required; elevated, if more than 90°, and depressed, if less than 90°. A moment's consideration will show that a practised hand is here necessary to catch the bubbles of such minute spirit-levels at the happy instant. This addition has the disadvantage of increasing somewhat the depth of the box, which is rather an objection in the eyes of military men. And, after all, allowing that an approximation may be made by it towards determining an elevation or depression, when the object is very near, I feel disposed to think that with distant ones, which necessarily subtend low angles, the result can never be depended on.

I may just notice a contrivance for enabling the observer to read large angles with the box sextant, namely, by placing a second index-glass below the other, and at right angles to it; and, having the arc doubly graduated, observations are then taken by looking through a different hole, placed opposite the usual one.

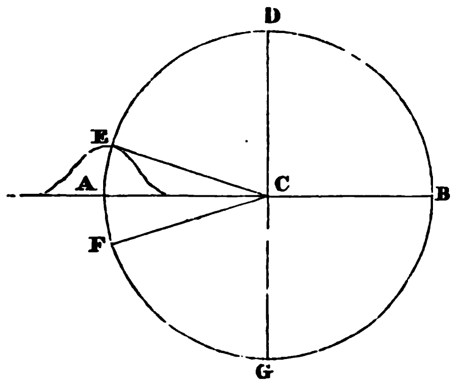
For military purposes this arrangement is objectionable, as it reduces the index-glasses to half the original size, and therefore injures the instrument for distant observations.

In order to render this chapter on the sextant as useful as possible, I shall take the liberty of extracting from Mr. Burr's "Practical Treatise on Surveying and Topographical Plan-drawing," a little contrivance that military men may chance to find of use for determining heights of mountains.

"It has been said in the preceding pages, that reflecting instruments require an artificial horizon to take altitudes; but we cannot use them for small altitudes, because the rim of the vessel containing the reflecting fluid renders it impossible, nor can we take depressions by such means: yet, as a military man may have occasion for such observations, and not possess an instrument provided with a vertical arc and level, we shall see how this may be done nearly, that is to say, within two or three minutes, by a reflecting instrument. Place three strong stakes across, like the triangle used for hanging a kettle, upon the ground, binding them firmly at the junction; across two of the legs tie a fine thread tightly, and place underneath any vessel containing a fluid, as mercury or water. Now, it is plain, that when we look from above, so as to bring the thread and its reflected image into exact coincidence, our eye will be a vertical plane; therefore, by resting upon the stakes, and bringing the reflected image of a

distant object into exact contact with the thread, we shall measure the supplement of the zenith distance; and if that is less than 90°, its complement will be the depression; but if above 90°, the surplus will be the elevation. This apparatus can be made anywhere; and we insert this expedient, in order to show that, with apparently slender means, we may do something."

I have found this simple expedient to answer very well for an approximation to the height of hills, buildings, &c., and shall add a diagram, which will assist my readers to understand it.

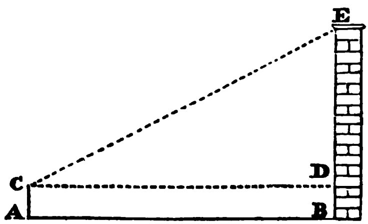


Let C represent the situation of the observer's eye, A B the horizon, and E the top of a hill. E D is then the zenith distance. By the method above given we measure the angle, E C G, which is, of course, the supplement of the zenith distance, E D; and, consequently, if we deduct 90°, or the angle, A C G, measured by the arc, A G—the angle, A C E, is left, namely, the elevation of E above the horizon. Again, for the depression—suppose our object is to obtain the depression of F—we measure the angle, F C G, the complement of which, or its difference from 90°, gives the angle, A C F, which is the depression of F.

The height and distance of objects, as walls or buildings, whether accessible or otherwise, may be obtained in a very simple and expeditious manner with the sextant, by means of the following table of tangents.

Multiplier.	Angle.	Angle.	Divisor.
1	45° 0′	45° 0′	1
2	63 26	26 34	2
3	71 34	18 26	3
4	75 58	14 2	4
5	78 41	11 19	5
6	80 32	9 28	6
8	82 52	7 8	8
10	84 17	5 43	10

Make a mark upon the object, if accessible, equal to the height of your eye from the ground. Set the index to one of the angles in the table, and retire on *level* ground, until the top is brought by the glasses to coincide with the mark; then, if the angle be greater than 45°, multiply the distance by the corresponding figure to the angle in the table; if it be less, divide; and the product or quotient will be the height of the object above the mark. Thus, let E B be a wall, whose height we want to know; and 26° 34′ the angle selected. Make a mark at D equal to the height of the eye then step back from the wall, until the top at E is brought down by the glasses to coincide with the mark: meas ure the distance, A B, nam ely



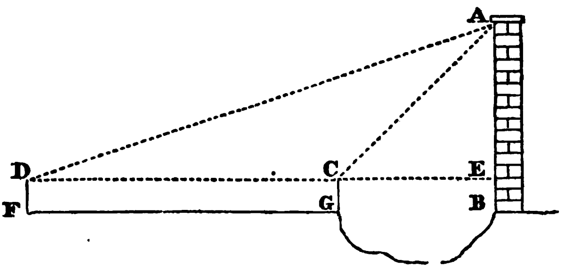
from your station to the wall, and divide that distance by 2, the figure corresponding to 26° 34′, this will give the height, D E, to which B D must be added.

The *parallax* of the instrument has been already mentioned and explained: it exerts an influence on measurements of this kind, from the object being near. To correct it, we have only to ascertain its amount, by placing the index at zero, and looking through the instrument at the top of the wall; when, if influenced by parallax, it will appear as a broken line; but by moving the index a little way on the *arc* of *excess*, or to the left of zero, the broken line will reunite, and the adjustment be effected. When any quantity is taken thus on the arc of excess, the amount must be considered when setting the instrument to any of the tabular angles.

When the object is inaccessible, set the index to the greatest of the divisor angles in the table, that the least distance from the object will admit of, and advance or recede till the top of it is brought down by the sextant to a level with the eye: at this place set up a staff, equal to the height of the eye. Then set the index to one of the lesser angles, and retire in a line from the object, till the top is brought to coincide with the staff set up to indicate the height of the eye: place a mark here, and measure the distance between the two marks; this, divided by the difference of the figures opposite the angles used, will give the height of the object above the height of the eye or mark. *For the distance*, multiply the height of the object by the numbers against either of the angles made use of, and the product will be the distance of the object from the place where such angle was used.

The above will be understood better by means of a diagram. Let A B be a wall not to be approached nearer than C; and we find, upon trial, that this distance admits of our using the angle 45°: assume a point E on the wall, as the height of the eye; then the index being set to 45°, fix yourself so that the glasses shall bring the top, A, to coincide

with E. At this point, place a staff, C G, equal to the height of the eye. Now select any one of the lesser angles from the tables—18° 26′ for instance—and retire until the



point, A, agrees with the top of the staff, C G, which occurs at F. Place a mark at F, and measure the distance from F to G; which divided by 2, the difference of the numbers opposite to the angles used, will give A E: to which add B E = C G, the height of the eye and the total height, A B, is obtained. Then, for the distance: the height, A E, multiplied by 3, its corresponding figure, will give the length, D E; and A E, multiplied by 1, will, in like manner, give G B = A E in this instance.

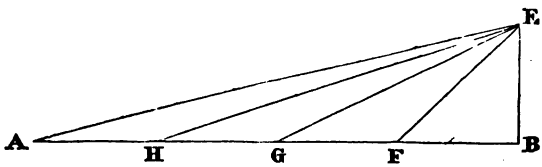
Horizontal distances as well as heights, may be ascertained by means of the table, where the ground is level. Thus, suppose we wish to measure the breadth of a river, denoted by the line A B: set the index to an angle of the table, place a mark at B, and proceed in a direction, C, at right angles to A B, until the glasses of the instrument show A and B in contact: then will the distance, A B,

be a product or quotient of the base, B C, according to the angle used. For instance, if the angle 26° 34′ be used, then must the distance, B C, be divided by 2.

The method of determining heights and distances by the tangent table is valuable, as the operations are speedily performed, and with tolerable accuracy; while it enables us to dispense with logarithmic tables and trigonometry.

The pocket sextant is very useful when taking off-sets: set the index to 90°, and walk along the station line; then when you wish to ascertain at what point any mark or object becomes perpendicular to the station line, you have only to look through the sextant at the left-hand object, and move forward or backward until the two objects, namely, the off-set mark and that on your station-line, are brought to coincide. Or, if you wish to lay off a line at right angles to another, send your assistant with a staff in the required direction, and having set the index at 90°, cause him to move right or left until his staff and your other mark are made to agree.

The student ought to know the principle upon which the tangent table is formed. In the figure below, B E is perpendicular to A B; and A H, H G, G F, and F B, are each equal to B E; join E F, E G, E H, and E A. Then,—



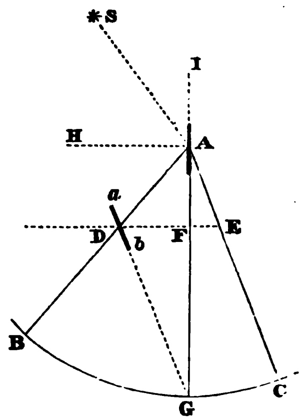
1st radius	: F B	::	tangent ∠ F	:	B E.
2nd ,,	: GB, or 2 B F	::	tangent ∠ G	:	B E.
3rd ,,	: HB, or 3 B F	::	tangent ∠ H	:	B E.
4th ,,	:"F B	::	tangent of the angle	:	B E.

Therefore,—

			Natural Tangent.	
Tangent $\angle$ F	= radius	= 1.	= 45°	0′
Tangent $\angle$ G	$= \frac{\text{radius}}{2}$	= ·5000000	= 26	34
Tangent $\angle$ H	$= \frac{\text{radius}}{3}$	= ·3333333	= 18	26
Tangent $\angle$ A	$= \frac{\text{radius}}{4}$	= ·2500000	= 14	2

PRINCIPLE OF THE SEXTANT.

We may here devote a brief space to an explanation of the principle upon which the sextant is constructed.



Let A B C represent a sextant, having an index, A G (to which is attached a mirror at A), moveable about A as a centre, and denoting the angle it has moved through, on the arc B C; also, let the half-silvered (or horizon) glass, *a b*, be fixed parallel to A C; now a ray of light, S A, from a celestial object, S, impinging against the mirror, A, reflected off at an equal angle, and striking the half silvered glass at D, is again reflected to E, the place of the observer's eye, where the eye likewise receives, through the transparent part of that glass, a direct ray from the horizon. Then the altitude, S A H, is equal to double the angle, C A G, measured upon the limb, B C, of the instrument.

For the reflected angle, B A G (or D A F), = the incident angle, S A I, and the reflected angle, *b* D E, = the incident, *a* D A = D A E = D E A, because *a b* is parallel to A C. Now, H A I = D F A = F A E + F E A; and D A E being equal to D E A, it follows that H A I = D A E

+ F A E. From H A I and D A E + F A E, take the equal angles, S A I and D A F, and there remains S A H = 2 F A E, or 2 G A·C; or, in other words, the angle of elevation, S A H, is equal to double the angle of the inclination of the two mirrors; D A G being equal to G A C.

Hence, the arc on the limb, B C, although only the sixth part of the circle, is divided as if it were 120°, on account of its double being required as the measure of C A B, and it is generally extended to 140°.

With respect to the comparative merits of the pocket sextant and prismatic compass for general surveying purposes, my own experience has led me to give a preference to the latter; as I have found that the error in measuring angles, between objects not in the same horizontal plane with the sextant, has been usually greater than that arising from estimating the minutes, *when using the compass with a stand*: but if this instrument be used without its stand, the sextant will in that case prove the most correct. It must be borne in mind, that for surveying roads, rivers, and boundaries of any kind, the sextant is not applicable. It is recommended that an officer supply himself with both instruments, both being necessary according to circumstances.

THE REFLECTING SEMICIRCLE.*

This is a kind of open sextant, a representation of which is given in plate XV., by which the angle taken is also protracted with perfect accuracy. It is a semicircle of brass, furnished with an index-mirror, A, and half-silvered horizon glass, E. There is a small hole at C for the observer to look through. K B is the index-arm, which is pushed open by the hand, and carries with it the mirror, A. D is

* We are indebted to that distinguished and scientific officer, General Sir Howard Douglas, for this military instrument.

a vernier adjusted to a graduated arc at the circumference. On the flat or ruler part there is a diagonal scale of four inches to a mile; and there is a corresponding scale on the fiducial edge. To measure an angle, the observer looks through the hole at C, and sees his left-hand object direct through the unsilvered part at E, while he moves the index-glass, A, by means of the arm B, until the other object appears on the silvered or lower portion of the horizon-glass, E, by reflection from the mirror, A. The angle is then protracted by means of the instrument itself; for the angle, N K B, formed by the ruler and arm, K B, is equal to the angle observed.

There is this difference in the construction of the semicircle from that of the sextant—that the index-glass being placed at the extremity, instead of at the centre, of a diameter, the angle observed agrees with the graduated arc; which is not the case with the sextant. [See Principle of the Sextant.]

This instrument is applicable to most purposes for which the sextant is used; but I am inclined to prefer the latter, considering it as less likely to be put out of order, and when so, to be easier of adjustment. It is also more convenient for holding during an observation, and may be considered more portable; as the semicircle must have a case for its protection.

THE OPTICAL SQUARE.

An instrument which has quite superseded the "surveying-cross," or "cross-staff," for setting off right angles and raising perpendiculars, called the optical square, has been derived from the sextant. It is made of brass, and contains the two principal glasses of the sextant, viz., the index and horizon glasses, fixed at an angle of 45°; hence, while viewing an object by direct vision, any other, forming a

right angle with it at the place of the observer, will be referred by reflection, so as to coincide with the object viewed. Thus a line may be laid out perpendicular to a station-line, and from any point on it, by simply standing with the instrument over the given point, and looking through it along the line, having a person to go with a mark or station-staff in the direction the perpendicular is required, and signing to him by hand to move to the right or the left, until his staff is seen by reflection to coincide with some object on the line along which the observer is looking, when the place of the staff will be in a perpendicular to the station-line at the place of the observer.

If it be required to find on a line the place of a perpendicular from a fixed object, as a house, &c., the observer himself must move along the line until the image of the object appears, as before, in the direction of the line, and the place where he then stands will be the spot where such perpendicular would fall. This instrument has the advantage of great portability, not being larger than a shallow circular snuff-box, which it resembles in shape.

DESCRIPTION AND USE OF THE PLANE-TABLE.—THE RECONNOITRING PROTRACTOR.

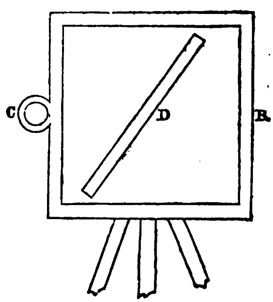
Although the plane-table has been in a great measure laid aside by English surveyors, both civil and military, some description of it, with an explanation of the manner of using it, ought to find a place in a manual of military surveying, especially as it is still in use at the Royal Military College.

Before the theodolite came into general use, the plane-table was a capital instrument among surveyors, and continued to be employed, both for filling in and making small surveys, long after the introduction of the theodolite. For

military purposes, the chief objection to the plane-table is the inconvenience of carrying it, even under its most portable form, as compared with the prismatic compass and sketching-case; but when surveys are not required to be performed with very great accuracy—such as the class of military sketches—they can be executed with great ease and rapidity by the instrument in question.

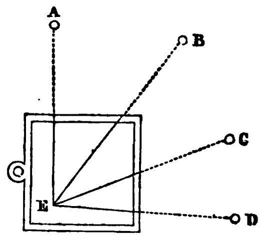
The old plane-table was an unwieldy affair, of some 15 or 16 inches square, which has very properly been discarded; and those surveyors who still adhere to this instrument, commonly use a board of from 10 to 12 inches square; they also reject the brass ruler furnished with sights, being contented with a common flat ruler.

In the adjoining figure, representing a plane-table, C is a small compass attached to the board; D is a ruler detached, and lying flat upon it; R is a rim or frame, which serves to confine the paper to the board. The instrument stands upon three legs.



"In preparing the plane-table for use" (says Mr. F. W. Simms), "the first thing to be done is to cover it with drawing-paper; the usual method of doing which is the same as that of covering a common drawing-board, by damping the under side of the paper, and laying it on the board in an expanded state; press the frame into its place, so that the paper may be squeezed in between the frame and the edge of the table; and the paper, shrinking as it dries, assumes a flat surface for the work to be performed upon. There is one great objection, however, to this mode of putting on the paper, as, when it has once been damped and strained, it is easily acted upon by

any change in the hygrometrical state of the atmosphere. We therefore prefer putting the paper on dry, taking care to keep it straight and smooth whilst pressing the frame into its place; but it must be acknowledged that this cannot be done so nicely as when it is damped. We have been informed that, if the under side of the paper be covered with the white of an egg well beat up, it may be laid on the board with the greatest nicety; and that when so prepared it is not easily affected by atmospheric changes."



To show the manner of using the plane-table, we will suppose that a military sketch of a portion of country is to be made, and that the first proceeding is to determine the situations of certain points, as A, B, C, D, and E. This is effected by measuring angles from each end of a base line, and determining the positions of the points by intersections, the same as if working with a theodolite or compass.

Let the line, A E, be considered as the base, whose length is to be ascertained by the chain or pacing. Set up the instrument at E, making it as level as possible, by shifting the legs, judging by the position of the compass-card when the board is nearly horizontal. Draw a line upon the paper, and lay off the distance from E to A; then insert a stout needle, fixed in a piece of wood, through the point, E, into the table; and having laid an edge of your rule along the line E A, turn the table in its socket, until the distant point, A, is found to be in line with the edge of the ruler; in which position the table must be firmly clamped, by means of a screw for that purpose. Observe the reading of the compass while the table is in that position, and you

will afterwards, wherever you may be, always have it in your power to set the table parallel to its first position, by giving the compass-card the same reading, and also be able to check your future operations. Keeping the edge of the ruler touching the needle, move it until it is in line with B, with C and D, drawing lines in succession in the direction of those objects.

This effected, the table is removed to A; and, in setting it up, be careful that the point representing A in the paper be exactly over the station-point and not the centre of the board. Fix the needle in the point, A, and having laid the ruler again along the line, A E, turn the table until its edge is found to be in line with the distant point, E; when the reading of the compass will be found the same as at the former station. Lines are then drawn in the directions of B, C, and D, which, intersecting those drawn from E, will give their respective situations on the plan.

If the plane-table is to be used for filling in between points previously fixed, some of the points are first transferred to a paper on the table; the instrument is then set up at one of those points, and, being turned round until a line joining that with another of the points is seen along the edge of the ruler to cut the distant object, the figure or lines transferred to the paper on the board are then known to correspond with those on the ground. The reading of the compass-card is then noted, and afterwards, at any point where the table may be set up in the course of operations, it will always be *parallel* to its first position, when the compass-card has the same reading.

To determine any particular place, such as the bend of a road or river, from whence two or more points already fixed can be seen, it is only necessary to set up the table over the point to be found, and turn it till the compass has the same bearing as at any one of the stations; when the

sketch on the table will be parallel, or correspond with the ground, if there is no local attraction to interfere with the needle. Clamp the table, and fix a needle in the point representing one of the stations; place the ruler in contact with this needle, and then turn the ruler until the station is seen along its edge, when a line is to be drawn on the paper. The needle is then removed to another station on the board, and, the same proceeding being gone through, the intersection of the two lines drawn on the board will give the required point. But, as a proof of its correctness, a third line from another station should, if possible, be obtained, which ought to pass through the same point.

The ingenious author of the Artillerist's Manual, Captain Griffiths, of the Royal Artillery, has recently put forth a surveying instrument of a very simple construction, which bears some resemblance to the Plane Table, but is, perhaps, superior to it. This instrument is called The Reconnoitring Protractor, and may be obtained, with instructions, illustrated by diagrams, for using it, at Messrs. Elliott's, 56, Strand.

Captain Griffiths states, "this instrument, simple in its construction, easily made when required, and economical in price, compared with the theodolite, pocket sextant, prismatic compass, &c., is not intended to supply the place of these instruments, when *very great* accuracy is required in surveying, or in trigonometrical observations; but, in the hands of officers accustomed to the use of it, angles may be rapidly taken, heights and distances ascertained, roads traversed, and trigonometrical calculations may be made with sufficient accuracy for a military survey, or reconnoissance.

"The Reconnoitring Protractor consists of a frame or block ten inches square, having attached to it an arm, (or

index), graduated in inches, with sights, adapted for elevations and depressions, to mark correctly the angles taken in the measurement of distances; which arm also acts as an index, or plummet, in ascertaining the height of a distant object. The protractor has the degrees marked on a raised marginal scale, which retains the paper in its place during the sketch; and one side of the instrument has a metal tube in it for ensuring accuracy of position in the measurement of distances, and also for taking the angular height of objects.

"The Reconnoitring Protractor has a tripod on which it may be steadily fixed for the purpose of taking the angles, &c., but the instrument can nevertheless be advantageously used without the tripod; and mounted officers, after a little practice, with the instrument alone, can satisfactorily make a survey or reconnoissance, especially if they are able to measure, or calculate the distances of base lines, by the length of the paces of their horses."

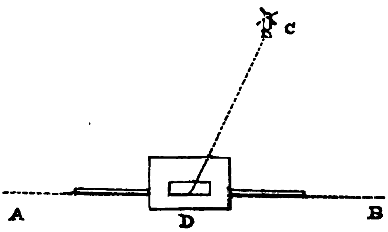
The purposes to which this instrument is applicable, are, 1st, traversing roads; 2nd, to ascertain the distance from inaccessible objects; 3rd, to measure the height of an inaccessible object; 4th, to measure the height of an accessible object; 5th, to measure the vertical height of a hill or mountain; 6th, to measure the altitude of a tower, &c., or a height.

As extreme accuracy is seldom required in ordinary military sketches, the instrument which enables an officer to get through his work most quickly will always be a valuable one. If a survey or sketch be found adequate to the occasion that has called it forth, it matters not whether a theodolite, compass, or other instrument, has been used in making it. As regards the reconnoitring protractor it is no doubt fully equal to the production of all that is necessary in a military sketch of limited extent, and the

profession has reason to feel grateful to Captain Griffiths for his very cheap and convenient instrument.

Before ending this section let me note a simple method of laying down a bearing, communicated by an old pupil of mine, Lieutenant Yule, Bengal Engineers, to whom I am indebted for other hints used in this work.

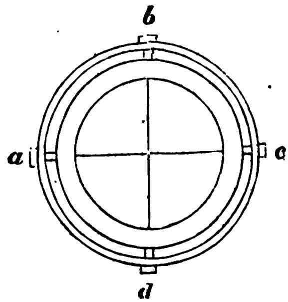
Having no angular instrument at hand, you want to lay down on a sketch the bearing of an object, C. Lay a straight walking-stick on the ground in the line A B, and placing the edge of your scale along A B in the sketch, hold your sketch book so that this edge shall coincide with the position of the walking stick below. This brings your book to be a sort of plane table; now draw D C by the eye in the direction of the object C.



SECTION XIV.

FURTHER DESCRIPTION OF THE THEODOLITE, WITH AN EXPLANATION OF ITS SEVERAL ADJUSTMENTS. [SEE PLATE VII.] DESCRIPTION OF THE PRISMATIC COMPASS—MERIDIAN LINE.

THE *telescope* should be of the achromatic kind, in order to obtain a larger field and a greater degree of magnifying power. In the focus of the eye-glass are two hairs at right angles to each other; they are of spider's thread, and attached by means of a little gum to a circular brass ring, smaller than the tube of the telescope. In this figure the outer circle represents a section of the tube of the telescope; the inner, a brass ring to which the threads are attached, fixed to the tube by the four small screws *a, b, c, d,* near the eye-end of the telescope. If the screw *a* be eased, while at the same time that at *c* is tightened, the ring will be moved to the right; and in the same way it may be moved up or down by turning the strews *b* and *d*. The object of this contrivance is to place the intersecting point of the threads in the centre of the telescope—its axis.



The object-glass of the telescope is moved by means of a milled nut, M, in order to suit the eye of the observer, and his distance from the object. The telescope rests on

supports, called Ys, which are fixed to the vertical arc, and so formed as to be *tangents* to the cylindrical rings encircling the tube of the telescope, and consequently the *bearing* is only upon two points in each Y.

The vertical arc, V, is graduated on one side to half degrees, and provided with a vernier reading to one minute. It is numbered each way from 0 to 45° or 50°, for taking angles of altitude or depression. On the other side of the vertical arc, a range of divisions is sometimes given for reducing hypothenusal lines to horizontal ones, or showing the difference between the hypothenuse and base of a right-angled triangle, always supposing the hypothenuse to consist of 100 equal parts; therefore, the number of feet to be deducted from each chain's length in measuring up or down a slope, in order to reduce it to the true horizontal distance, is seen at once.

The horizontal circle, H, consists of two plates, one moveable on the other. The upper, or index-plate, carries a vernier scale, adjusted to the divisions of degrees and half-degrees of the lower plate. The index-plate (together with the compass, vertical arc, and telescope,) turns on its axis independent of the lower plate; which latter turns on the same axis, but is fixed in any position by tightening the clamping-screw, A. The screw, P, fastens the two plates together, when the upper plate may be made to move a short distance by turning the tangent-screw, N. The horizontal circle is divided into half degrees, and numbered from 0 to 360° or 180°. The vernier scale subdivides the half degrees to one minute or less, according to the size of the instrument.

The compass is fixed on the upper plate. It is divided to 360°, numbered contrary to the horizontal circle. The letters E and W are generally transposed; the use of which

is that, in taking a bearing, 50° west for instance, the needle remaining stationary shows 50° towards W, or west. But with the letters properly placed, the needle would point to 50° between the N and E points.

THE ADJUSTMENTS OF THE THEODOLITE.

Every one using the instrument ought to be able to adjust it for himself. The first adjustment is that of the line of sight, or of collimation as it is termed; which is to place the intersection of the cross hairs exactly in the centre or axis of the cylindrical rings of the telescope resting on the Ys. To effect this, place the theodolite on its legs, and direct the telescope so that the centre of the horizontal hair shall coincide with some well-defined part of a distant object; then turn the telescope in the Ys till the level is uppermost: observe then whether the horizontal hair still coincides with the object, if so, the hair is in its right position; if it do not so coincide, correct *half* the difference by moving the hair, which motion is effected by easing one of the hair-screws, *a, b, c,* and *d,* and tightening its opposite; after which, turn the telescope in the Ys till the level tube is underneath, and make the horizontal hair coincide with the object, by moving the vertical arc, V; again turn the telescope till the level is uppermost, and if the hair do not cut the same part of the object, the above operation must be repeated till, in both positions of the telescope, the horizontal hair cuts the same part of the distant object. The horizontal hair being thus adjusted, turn the telescope until the other hair is placed in a horizontal position, and proceed as before. When the two hairs are thus adjusted, their point of intersection will coincide exactly with the same point of the distant object

while the telescope is turned round; and the hairs are not properly adjusted till this is effected.

The second adjustment is that which puts the level attached to the telescope parallel to the rectified line of collimation. The clips, *i i*, being open, and the vertical arc clamped by turning the screw, C, bring the air-bubble of the level to the centre of its glass tube, by turning the tangent-screw, D, which gives a slow motion to the vertical arc; this done, reverse the telescope in its Ys, that is, turn it end for end, which must be done carefully, that it may not disturb the vertical arc, and if the bubble resume its former situation, in the middle of the tube, all is right; but if it retire to one end, bring it back one half by the screw, R, which elevates or depresses that end of the level, and the other half by the tangent-screw, D, of the vertical arc: this process must be repeated until the adjustment is perfect.

The third adjustment is that which makes the azimuthal axis, or axis of the horizontal circle, truly vertical.

Set the instrument as nearly level as can be done by the eye, fasten the centre of the lower horizontal plate by the clamping-screw, A, leaving the upper plate at liberty, but move it till the telescope is over two of the parallel plate-screws; then bring the bubble of the level under the telescope to the middle of the tube, by the screw, D; now turn the upper plate half round, that is, 180° from its former position; then, if the bubble return to the middle, the plate is horizontal in that direction; but if otherwise, half the difference must be corrected by the parallel plate-screws, over which the telescope lies, and half by elevating or depressing the telescope, by turning the tangent-screw, D, of the vertical arc: having done which, it only remains to turn the upper plate forward or backward 90°, that the telescope may lie over the other two parallel

plate-screws, and, by their motion, set it horizontal. Having now levelled the horizontal circle, by means of the telescope level, which is the most sensible upon the instrument, the other air bubbles fixed upon the vernier plate may be brought to the middle of the tubes, by merely giving motion to the capstan-headed screws at each end of them.

The vernier of the vertical arc may now be attended to: it is correct, if it points to zero, when all the foregoing adjustments are perfect; and any deviation in it is easily rectified, by releasing the screws by which it is held, and tightening them again after having made the adjustment, or, what is perhaps better, note the quantity of deviation as an index error, and apply it, plus or minus, to each vertical angle observed. This deviation is best determined by repeating the observation of an altitude or depression in the reversed positions, both of the telescope and the vernier plate: the two readings will have equal and opposite errors, one half of the difference being the index error. Such a method of observing angles is decidedly the best, since the mean of any equal number of observations, taken with the telescope reversed in its Ys, must be free from the effects of any error that may exist in the adjustment of the vernier or zero of altitude.

It is of great importance that the telescope and vertical arc should move in the same vertical plane: in small theodolites, this is provided for by the construction, and no means are afforded for making any alteration; but larger instruments are furnished with screws for this adjustment. To prove the accuracy of the vertical arc, suspend a weight by a long plumb line from a branch of a tree, or otherwise, and adjust the cross hairs upon it; then, by means of the elevating screw, cause the vertical arc to rise, and observe whether the cross hairs continue on the

line while the vertical motion continues. Or fix them on the angle of a lofty building, and raise or depress the telescope, when the cross hairs will continue to move on the angular line if the adjustment be perfect. For depression, a reflection of the same angle of a building from an artificial horizon will serve as a test.

DESCRIPTION OF THE PRISMATIC COMPASS. [PLATE I.]

The box contains a card under which, and attached to it, is a magnetic needle; the whole nicely suspended on an agate point, so as to allow of the card playing freely. The circumference of the card should be divided to one third of a degree, or 20 minutes; but a bearing may be estimated to within three or four minutes, when the compass is mounted on a stand. On looking through the slit at A, the eye, by means of a triangular prism, sees at the same time the thread, B, and the compass-card, in such a manner as to make the divisions on the card seem a continuation of the thread; and the division with which the thread coincides, when the needle is at rest, is the magnetic azimuth of whatever object the thread may bisect. A hinge-joint connects the prism with the box, and enables it to be turned over in a convenient position to fit into the case. The sight-vane, B, has a fine thread stretched along its opening in the direction of its length, which is brought to bisect any object by turning the box round horizontally; the vane also turns on a hinge-joint, and can be laid flat upon the box for the convenience of carriage. A little knob (not seen in the figure) touches a spring, by which the vibrations of the card are checked for speedier adjustment to an object; and C is a little lever by which the card is thrown off its centre; which should always be done when the instrument is not in use, as the constant playing of the needle would wear the point upon which it is

balanced, and upon the fineness of the point much of the accuracy of the instrument depends. The milled head, D, fixes the compass, when required. There is a cover to the box, which is about three inches in diameter, and one in depth.

The method of using the instrument is very simple:—Having fixed it on the stand, place it immediately over the station-point, spreading the legs so as to give sufficient firmness; observe that the card is level, or nearly so, in order that it may play freely; then raise the prism, by means of the slide at E, until the divisions of the compass-card are distinctly seen; now look through the slit, A, and turn the box round, until the thread, B, bisects the object you are observing: allow the card to settle, and the division on the card which coincides with the thread of the vane will be the azimuth, or bearing of the object, reckoned from the north or south point of the needle, when the card is divided into twice 180°, as I recommend.

The angular distance between any two objects will, of course, be the difference of their bearings; thus, suppose one to bear 15° N. E., and the other 165° S. E., the angular distance between them will be 150°.

In military sketching, the compass is often supported by the hands, when the little spring, to check the vibrations of the card, is very useful. In windy weather it is necessary to watch these vibrations, and adopt the mean as the bearing sought. When held in the hand, this instrument will give a bearing to within about 15 minutes: but if there be much wind, it will not be nearer, perhaps, than half a degree of the truth.

Dark glasses are sometimes fixed to the prism-case, and a mirror also to the sight-vane: these are used when taking azimuths of the sun. They add to the cost of the

instrument; and, being seldom required, I recommend officers to dispense with them, when they want a compass for ordinary surveying purposes.

Having given a sufficiently minute description of the instruments commonly used by military men, and explained their several adjustments, it only remains for me to point out those among them that will be found generally useful.

With regard to the theodolite, which is unquestionably the best instrument employed in surveying, it may be observed, that an officer seldom finds it necessary to provide himself with one; as, whenever he is employed on an extensive survey, proper instruments will be furnished him for the duty: besides the theodolite is much too cumbersome an instrument to form any part of his personal equipment. Field instruments, as the compass, sextant, &c., he must have of his own.

I should imagine that, in the course of the preceding pages, it has been sufficiently shown, that a good prismatic compass is adequate to every purpose of ordinary military sketching. With a tripod stand, which is essential, we are enabled to obtain bearings with considerable accuracy; at least, they will be near enough to the truth for any ordinary military purpose.

The box-sextant is an excellent little instrument, as I think we have proved; but unlike the compass, it will not do alone. With it we cannot lay down a meridian line, nor can we find our place on a plan, by knowing the situations of two others; neither can we use it for surveying roads, rivers, &c.: all objects of absolute necessity in military sketching.

I shall say nothing here of the reflecting semicircle, as the remarks on the sextant apply equally to that instrument.

OF THE MERIDIAN LINE.

All surveys should have a *true* meridian laid down on them, as well as the magnetic one; which last is variable. Any person using a map or plan, immediately begins to refer all imaginary lines connecting towns or villages, as well as the directions of roads, rivers, ridges of hills, &c., to the cardinal points—this is his first step towards an acquaintance with the country by means of a map.

When the *variation* of the needle is known correctly, a true meridian line is laid down with sufficient accuracy for ordinary military surveys by means of a good compass; as we have then only to draw a line, making an angle, equal to the amount of variation, with the magnetic meridian by which we have been working. But the exact variation is not so easily obtained as some may suppose; since the most careful observations, with very delicate instruments, will often give fallacious results, owing to local attraction or other causes, of which we are not conscious. For instance, at sea the body of the ship exercises so much influence on the needle, that an observation may be thrown some degrees wide of the truth.

While on the subject, I may mention that the cause of the variation has never been satisfactorily ascertained. If our records be correct, the variation was at London in 1580, 11¼° E.; in 1622, 6¼° E.; in 1634, 4° E., since which it has continued gradually deviating westerly, at the rate of about 12′ annually. In 1838, the variation, as found by observation at the Royal Observatory, was 24° 6′ W.; which, I have reason to believe, was the maximum, and that the variation has been decreasing from that period. It is to be observed, however, that the variation alters as we change our place on the earth's surface.

The following method of roughly laying down a meridian line is given in Major Sir T. L. Mitchell's little book on surveying, and will do very well for ordinary occasions; it is, moreover, particularly suited to an officer, who has seldom good astronomical instruments at command.

"Let a plummet be suspended, so as nearly to touch the smooth surface of a table placed truly horizontal, from the point of a thin but steady rod attached to the table, and inclined over the middle of it at an angle of about 45°. When the plummet is still, mark the point exactly under it on the table. The table may then be conveyed to any point laid down on the plan, and adjusted to the horizontal position by means of the plummet, which will, in that case, cover the point previously marked. At 9 o'clock *a. m.*, and at 3 *p. m.*, according to a good time-piece, mark on the table the point of the shadow of the rod, and draw a line from each of these points to the point under the plummet. These lines, if the watch is correct, will be equal in length, and at the equator would form one straight line, a perpendicular to which, at the plummet point, would be in the direction of the meridian; and, at other parts of the earth, the meridian will be in the direction of a line bisecting the angle formed by shadows of equal length. This simple method may be adopted with equal accuracy without a time-keeper, by marking the point of the shadow some hours before mid-day, and of that shadow also which is cast of equal length in the afternoon. This corresponding length of the afternoon shadow may be found by the repeated application of any measure equal to the length of the morning shadow.

"It may be more convenient to mark shadows at different intervals in the morning, in order that one corresponding in length may be found with less delay in the afternoon; or, for the sake of greater accuracy, several

corresponding respectively to distances marked by points of morning shadows. One line will bisect all the angles contained between equal sides, and that line will be in the direction of the meridian.

"When this line has been determined on the table, it may readily be connected with the ground, by inserting needles at the two extremities, and looking along them to any object on the horizon with which they may coincide. When this object happens to be one laid down on the plan, the line between it and the station will be that of the north and south; when it is not a point laid down on the plan, the angle must be observed between it and any fixed point: the direction of the meridian line may then be laid down by protracting that angle."

SECTION XV.

MENSURATION OF PLANES — SURVEYING WITH THE CHAIN —METHOD OF CONDUCTING A SURVEY — PLOTTING THE SURVEY.

Our civil surveyors rarely employ any instrument but the land-chain in surveys of limited extent, such as those of parishes, estates, &c.; and it must be admitted that the system is well adapted to the kind of work they are usually called upon to perform. Although military men may not often have occasion to survey with the chain alone, yet is a knowledge of the system very desirable; since it is upon that system they would work in the event of having no angular instrument at hand. Moreover, it is considered that a knowledge of chain-surveying is, for young pupils, the best introduction to angular and trigonometrical surveying, and hence it has long been practised at the military colleges of Woolwich and Addiscombe.

Two measuring chains are in use among surveyors, viz.: one of 100, the other of 66 feet in length; both, however, being divided into 100 links; and therefore, while the link of the first measures 12 inches, that of the other is only 7·92 inches. The latter, called Gunter's chain, is very convenient for the computation of superficial measure, 10 square chains being equal to an acre; and as the chain is divided into 100 links, the content of a field or other enclosure given in chains and links, is converted into acres and decimals of an acre, by simply dividing by 10.

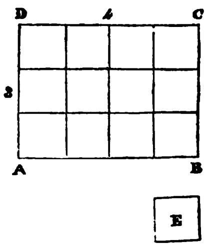
A few words on the mensuration of planes will here be of service.

MENSURATION OF PLANES.

The area of any plane figure is the measure of the space contained within its lines or bounds.

This area or content is estimated by the number of squares that may be contained in a figure; the length and breadth of those squares being an inch, a foot, a yard, an acre, or any other fixed quantity. And hence the area or content is said to be so many square inches, square feet, square yards, &c.

Thus, if the figure to be measured be the four-sided one, ABCD, which is termed a rectangle (its four angles being



right angles), and the little square, E, whose side is one inch, be the measuring unit proposed: then, whatever number of those little squares may be made to fit into the figure, so many square inches it is said to contain; which in the present case is 12.

TABLE OF SQUARE MEASURE.

144	Square Inches *make*	1	Square Foot . . .	*Ft.*
9	Square Feet	1	Square Yard . .	*Yd.*
30¼	Square Yards. . . .	1	Square Pole . . .	*Pole.*
40	Square Poles	1	Rood.	*Rd.*
4	Roods.	1	Acre	*Acr.*

Sq. In.		*Sq. Ft.*		*Sq. Yd.*		*Sq. Pole.*		*Rd.*		*Acr.*
144	=	1								
1296	=	9	=	1						
39204	=	$272\frac{1}{4}$	=	$30\frac{1}{4}$	=	1				
1568160	=	10890	=	1210	=	40	=	1		
6272640	=	43560	=	4840	=	160	=	4	=	1

62·7264 Sq. Inches = 1 Sq. Link.
625 Sq. Links = 1 Sq. Pole or Perch.
10,000 Sq. Links = 1 Sq. Chain.
25,000 Sq. Links = 1 Sq. Rood.
10 Sq. Chains = 1 Sq. Acre.
100,000 Sq. Links = 1 Sq. Acre.

A *pole, perch,* and *rod,* are the same measure.

Now, the rule for finding the area of a rectangle is to multiply the length of the base by the height. In the figure above, this base is called 4 inches, and perpendicular 3 inches; and $3 \times 4 = 12$ square inches.

To find the area of any parallelogram, whether it be a square, a rectangle, a rhombus, or a rhomboid.

Multiply the length, stated in any linear measurement, as inches, links, feet, yards, &c., by the perpendicular height, and the product will be the area.

Example :—To find the area of a parallelogram, whose length is 12·25 feet, and breadth or height 8·5 feet.

$$\begin{array}{r l} 12{\cdot}25 & \text{length.} \\ 8{\cdot}5 & \text{breadth.} \\ \hline 6125 & \\ 9800 & \\ \hline 104{\cdot}125 & \text{area.} \end{array}$$

Gunter's chain being 4 poles, or 22 yards, or 66 feet, in length, divided into 100 links; each link is therefore, $\frac{22}{100}$ of a yard, or $\frac{66}{100}$ of a foot, or 7·92 inches.

Land is estimated in acres, roods, and perches. An acre is equal to 10 square chains, or as much as 10 chains in length, and 1 chain in breadth. Or, in yards, it is $220 \times 22 = 4840$ square yards. Or, in poles, it is $40 \times 4 = 160$ square poles. Or, in links, it is $1000 \times 100 =$ 100,000 square links: these being all the same quantity.

Also, an acre is divided into 4 parts, called roods, and a rood into 40 parts, called perches, which are square poles—or the square of a pole of $5\frac{1}{2}$ yards long—or the square of $\frac{1}{4}$ of a chain—or of 25 links, which is 625 square links. So that the divisions of land measure will be thus:—

625 square links = 1 pole or perch.
40 perches . . . = 1 rood.
4 roods . . . . = 1 acre.

The lengths of lines, measured with a chain, are best set down in links as integers, and not in chains and decimals. Therefore, after the content is found, it will be in square links; then cut off five of the figures on the right hand for decimals, and the rest will be acres. These decimals are then multiplied by 4 for roods, cutting off five figures as before, and the decimals of these again by 40 for perches, when five figures are again to be cut off.

EXAMPLE.

Suppose the length of a rectangular piece of ground be 792 links, and its breadth 385; to find the area in acres, roods, and perches.

$$\begin{array}{r} 792 \\ 385 \\ \hline 3960 \\ 6336 \\ 2376 \\ \hline 3{\cdot}04920 \end{array} \qquad \begin{array}{r} 3{\cdot}04920 \\ 4 \\ \hline {\cdot}19680 \\ 40 \\ \hline 7{\cdot}87200 \end{array}$$

Ans. 3 *acres,* 0 *roods,* 7 *perches.*

Some mention has been made of the chain in Section VII.; but, now that we are on the subject of *Chain Surveying*, it must be more particularly noticed; and I cannot do better than avail myself of the clear instructions for applying it, which I find laid down by Mr. Butler Williams in his "Practical Geodesy," a work which I strongly recommend to all persons desirous of acquiring a knowledge of surveying in general:—

"To guide the eye in counting the number of links, brass marks are fastened at every tenth link of the chain, and distinguished from each other by notches, each varying in number according to their position with respect to the extremity of the chain; so that the surveyor can, by simple inspection, readily read any number of feet required.

"Accompanying the chain are 10 arrows, which are used in succession to mark the end of the chain in measuring a line.

"The chain is used by two persons, one of whom is called the leader, the other the follower. The point from which the measurement is to commence, as also the direction of the line to be measured, being determined, the leader, who has been supplied with the 10 arrows, stretches the chain in the required direction, while the follower keeps one end of it at the starting point. An arrow is then thrust perpendicularly into the ground by the leader, at the point where the chain terminates; he then proceeds onward, drawing the chain after him, and repeats the same operation throughout the length of the line, the arrow last put down serving always as the mark to which the follower is to bring his end of the chain as a new station of departure.

"The arrows are taken up by the follower as he advances, and, when the ten arrows have thus changed hands, they are all to be returned to the leader to be used again.

In this manner the arrows are changed from one to the other, at every 10 chains' length, till the whole length of the line is measured, care being taken to enter every such change in the field-book. At the end of the line, the number of changes, added to the number of arrows in the follower's hand, and to the number of links extending from the last arrow put down to the extremity of the line, gives the entire length measured.

"In the operation just described, care is necessary, first, to ensure that the line gone over is a straight line: secondly, that the ends of the chain have been made to coincide as accurately as possible with the arrows placed to mark each extremity, as any deviation from a straight line causes the apparent length measured to be greater than the true length.

"The length of the chain should, from time to time, be tested by a careful comparison with a standard chain kept for the purpose. To facilitate this comparison, two strong pickets may be driven firmly on a level portion of ground, at a distance of 100 links from each other; and, the standard chain being stretched from one to the other, notches are cut or nails driven marking the exact length of the 100 links. The coping of a horizontal wall is also well suited to receive such marks. They are thus rendered permanent, and every day a comparison of the working chain may be made with the standard length without loss of time. This precaution is indispensable; for the chain being composed of numerous pliable links joined together by three small unwelded rings, which give it flexibility, is, from its construction, constantly liable on the one hand to expand at the joints, and on the other to have the links bent when dragged over rough surfaces. Of such importance is this examination held by scientific and practical men that the Commissioners for the Restoration of the

Standards of Weights and Measures recommend in their report, dated December 21, 1841, that 'no person shall be admitted to give evidence in any court of justice of having measured land, after the passing of the contemplated act, with any other than a stamped (standard) measure, or a measure which has been compared on each day on which any part of the measurement has been made with a stamped (standard) measure.' The chain used for measuring may be left unaltered, if it be about half an inch longer than the standard, as it can never be stretched perfectly straight, but adapts itself by its weight to the small inequalities on the surface of the ground. The chain also, when used in wet weather, becomes shorter, in consequence of the insertion of dirt between the rings. If the excess be great, the length must be diminished by the removal from each extremity of one or more of the rings. The same correction, whatever it be, should be made equally at both extremities, in order that the middle point of the chain may be in its true position, in which case the error, subdivided among the remaining parts, will be trifling, and not worth being taken into account. If, on the contrary, the working chain be found too short, this will arise from the links being bent: consequently by straightening them the correction is effected.

"In measuring an estate, a parish, or any comparatively small portion of land, the surface may be supposed to be divided into a system of arbitrary geometrical figures bounded by right lines, either inscribed within or circumscribing the area to be measured; but so disposed that they shall pass near all objects included in the survey, and serve to determine their positions and forms. The object of this imaginary division is to facilitate the measurement of all irregular boundaries, which, if they were traced independently of these auxiliary lines, into all their windings,

would lead to a great consumption of time in the operation and to inaccuracy in the results, owing to the number of mutually dependent angles to be measured. After having divided the surface into a number of geometrical figures bounded by right lines, the sides of these figures are used as bases from which the irregular boundaries and other objects are measured by means of shorter lines at right angles, termed off-sets.

"These off-sets, when short, are measured with an off-set staff 10 links in length; with a second chain, or, in preference, a measuring tape, when the off-sets are too long for the staff to measure them conveniently. The limit to the length of these off-sets is fixed in a great measure by the degree of accuracy aimed at in the survey as well as by the scale to which the plan is drawn; in general it is not advisable to make use of off-sets more than about 100 feet in length. Off-sets, with few exceptions, are measured at right angles to the main line: the length of the off-set being once determined, the position of the object referred to is fixed with reference to the main line."

SURFACE TO BE DIVIDED INTO TRIANGLES.

"In making a survey with the chain only, we are confined to one, and the simplest, geometrical figure,—namely, the triangle; for, of all plane geometrical figures, it is the only one of which the form cannot be altered, if the sides remain constant.

"The surface to be measured is, therefore, to be divided into a series of imaginary triangles; and, in this division, it must be borne in mind that the triangles are to be as large, with reference to the whole surface to be measured, as is consistent with the nature of the ground; for, by such an arrangement, we are acting on this important principle in all surveying operations, that it is well always to work

from a whole to the parts, and rarely from the parts to a whole. By the first method, errors are subdivided, and time and labour economized; by the second, the errors inseparable from all operations that do not deal with abstract quantities are increased as each step in the work advances.

"The sides of these triangles are first measured; and, as a necessary check on this first part of the work, a straight line is in addition measured from one of the vertices to a point in or near the middle of the opposite side. This fourth line is called a tie-line, or proof-line, and is an efficient means of detecting errors, if any have been committed in the admeasurement of the sides of the triangle. This fourth measurement is made in accordance with a maxim which ought invariably to be acted upon in all surveying operations, whether limited or extensive, simple or complex; namely, that, where accuracy is aimed at, the dimensions of the main lines, and the positions of the most important objects, should be ascertained or tested by, at least, two processes independent one of the other.

"Within the larger triangles, as many tie-lines and smaller triangles are to be measured as may be necessary to determine the position of all the objects embraced in the survey. The directions of the lines forming the sides of the secondary triangles are so selected or disposed that they shall connect, and pass close to, as many objects as possible, so that the off-sets to be measured from them may be as short, and as few in number, as practicable.

"If the sides of these secondary triangles be in any case so distant from the objects whose positions are to be determined as to require a length of off-set greater than the proposed limit of about 100 feet, it then becomes advisable to construct, either on the whole or part of the side of the triangle, as a base, a smaller off-set triangle,

with the sides so disposed that they shall either embrace, or pass very near to, the objects to be measured by their intervention.

"The disposition and general combination of these triangles demanding care and judgment, it is customary, previous to commencing any measurement, to walk over the ground for the purpose of obtaining a general knowledge of the surface, and of the relative positions of the most conspicuous objects. The acquisition of this knowledge, depending on the *coup d'œil,* is much assisted by an eye-sketch drawn with rapidity, and showing some of the principal roads, streams, churches, &c. This hand-sketch is not to be drawn to any scale; and its object is attained if it simply bear a general resemblance to a plan of the ground, as it will thereby assist the memory in the distribution of the surface into triangles.

"The sides of the larger triangles are to pass as close as possible to the external boundaries to be surveyed; the triangles should, moreover, be made to approach, as nearly as practicable, to the form of equilateral, avoiding with care very acute or obtuse angles, because the farther the form of the triangle is removed from the equilateral, the greater will be the alteration in the form of the figure and in its area should any error have been committed in the measurements of any of the sides.

"The triangles having thus been disposed to the greatest advantage, marks or pickets are placed on the ground at each vertex of the triangles. Their general form and position is then noted on the hand-sketch previously made, and distinctive letters are written on the diagram at each point of intersection. This arrangement admits of easy reference in the field-book, or on the ground, to any triangle or part of a triangle.

"The points of intersection of all straight lines, as well

as the vertices of the triangles, are always points measured to or from: they are called station-points, or stations, and the lines connecting them station-lines, thereby distinguishing them from the simple off-set lines."

THE FIELD-BOOK.

"The hand-sketch or rough diagram is usually made in the field-book—that is, a book in which every minute step of the operations gone through in the survey is to be entered with precision at the time. The entries in the field-book should be made with an indelible pencil, or written in ink in the field; but the first is to be preferred, as it is difficult to make legible entries in ink in wet weather. The field-book should be paged for convenience of reference.

"The field-book is ruled into three columns: in the middle one are set down the distances on the station-line, at which any mark, off-set, or other observation is made: and in the right or left hand column are entered the off-sets and observations made on the right or left hand respectively of the station-line.

"It must be borne in mind that the middle column in the field-book represents the position of, or rather, the station-line itself. If the station-line, therefore, should be crossed on the ground by a fence, or any boundary meeting it obliquely, its representation or type in the field-book must not be made to pass obliquely across the middle column, but must arrive at one side of the column and leave it on the other, at points precisely opposite, as it would do were the middle column merely of the thickness of a line. Inattention to this particular causes much confusion in the relative position of off-sets.

"It is a universal rule, and of advantage for the sake of perspicuity, to begin the entries in the field-book at the

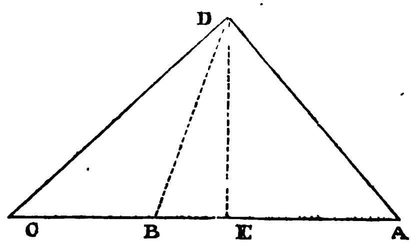
bottom of the leaf; the reason is evident, inasmuch as it places the field-book in the same position at the station-line with respect to the surveyor, who keeps his face directed towards the distant station. The crossings of the fences, roads, streams, &c., and the corners of fields, and other remarkable turns in the boundaries to which off-sets are taken, are to be shown by joining lines in a manner somewhat similar to the form which they assume on the ground. It is a too common error with the inexperienced surveyor to neglect this approximation to the real forms of the objects, as also to make his entries faintly, and with a careless hand. It cannot be too strongly impressed on the surveyor, that the work which he is called upon to perform depends, for its accuracy, in a very great measure on the order, system, and neatness bestowed on all the steps, whether of delineation or of measurement. Proper attention in keeping the field-book saves much time in plotting, and guards against the errors unavoidably arising from reference to a confused field-book. Moreover, care bestowed in the first essays will amply reward the surveyor, by giving accuracy of eye, freedom and steadiness of hand—qualities indispensable to his success."

The following example shows the way in which the field-notes may be entered when measuring a triangular piece of ground:—

From B	687	to D, proof-line.
	862	to A
From	D	
	956	to D
From	C	
	1265	to C
	800	B, point for proof-line.
From	A	

In these notes the letter corresponding to the starting-point in the rough diagram is entered at the bottom of the chain column, and the letter answering to the point to which measurement is made, stands on the right, opposite the distance entered: the first line, A C, therefore, reads in the field-notes from A 1265 to C.

A figure is easily constructed from the notes, by taking the three measured lengths, and forming with them a triangle, as below:—



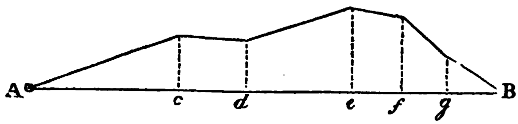
And then, having made the distance, A B, 800 from the same scale as the one from which the sides of the triangle were taken, the surveyor may be satisfied that his work is correct, if the proof-line, B D, measures 687 on the scale.

To find the area of the above figure, let fall a perpendicular from D, to the base line, C A; measure the length of the perpendicular on the plan, and apply it to your scale, which will give its length in links: then, having the base and perpendicular, proceed to calculate the area, which is 4 acres, 0 roods, 15 poles; the perpendicular being 640.

Method to be pursued when a boundary line does not run straight.

For example:—Suppose the waving line from A to B is to be surveyed.

Place a mark at A, and another at B; then measure from



A toward B, taking off-sets to each part of the boundary presenting a curve or an angle; observing, with reference to a curve, to take the off-sets, so that a right line drawn frem the end of one off-set or perpendicular to the end of the next shall neither exclude any portion of the land to be measured, nor include any of that which is adjacent.

The following are field-notes to the above figure:—

	1503	to B
133	1324	*g*
173	1187	*f*
268	1020	*e*
150	688	*d*
169	470	*c*
From	A	

Surveyors commonly divide an estate or a parish, which is to be surveyed, into one, two, or more great triangles, and the angular points being visible from each other, they are enabled to measure straight lines connecting them, by which the triangles can be laid down upon paper. If the line be so long, or on such uneven ground, that the staff fixed at its extremity be occasionally lost sight of, the line must be ranged with the telescope of a theodolite from a commanding position, care being taken that the axis of the telescope be truly in the line: ranging rods are with its assistance placed at convenient distances in the right line. In measuring these long lines, notes are kept in the field-book to show at what distances along them fences, roads, rivulets, &c., are crossed. Other lines within the large

triangles are then measured; and off-sets are taken to boundaries, fences, &c.; all observations being carefully noted in the field-book, until sufficient measurements have been made, by which to lay down all the boundary lines, fences, &c., contained within the limits of the ground to be surveyed.

It will be necessary to attend to the following rules in carrying on a survey of this description:—

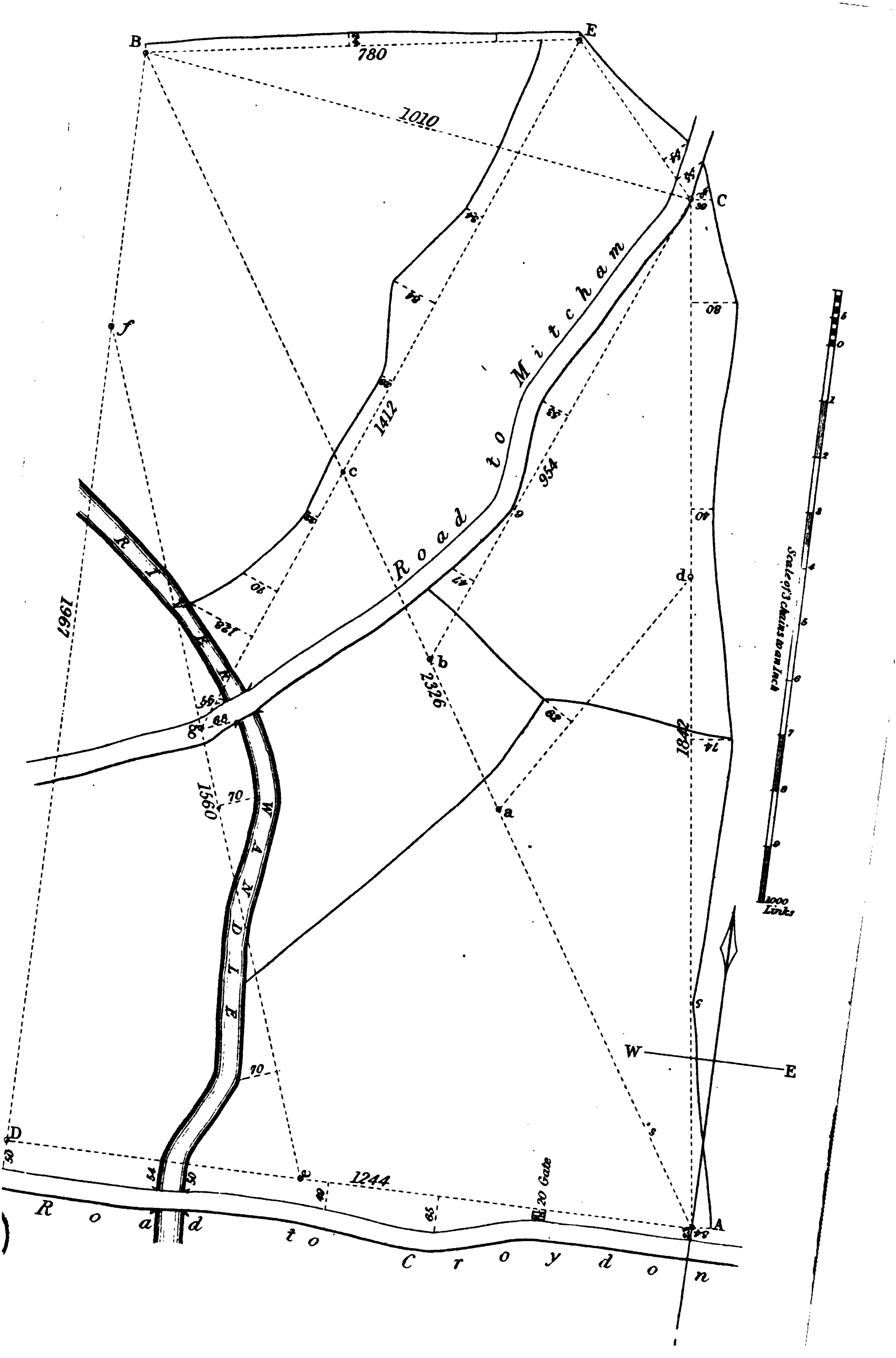
1. Be in no hurry to commence operations, but walk two or three times over the ground in order to get a perfect idea of it: and, to help your memory, a rough sketch on paper by the eye is recommended.

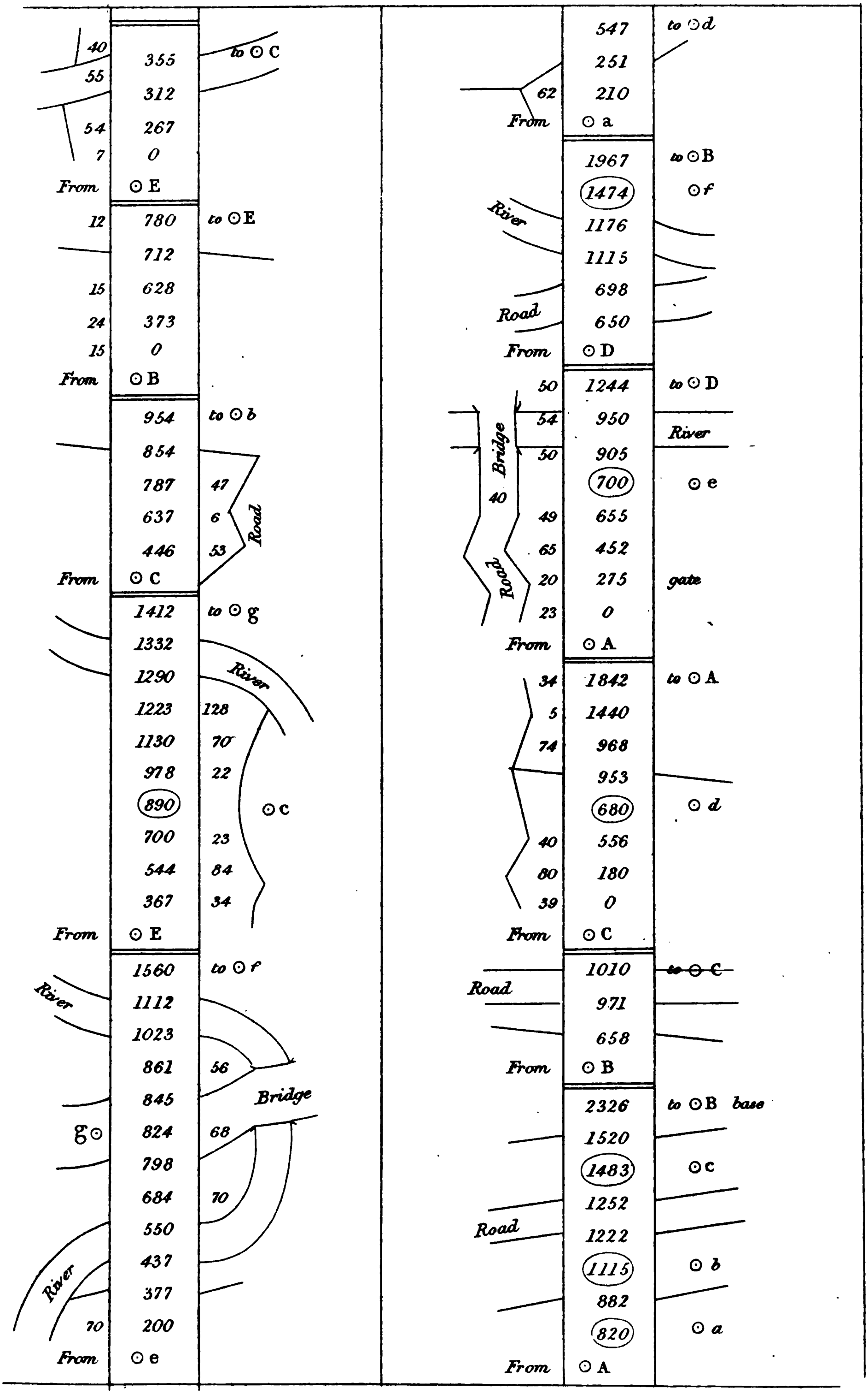
2. Select two points from which you can see to a considerable distance around; let these stations be as far from each other as possible; let them be near the boundaries of the ground, and so situated that a line connecting them shall be a kind of diagonal across it, forming what surveyors call a "main line;" which is to serve as a base for after-operations.

3. Fix on a suitable station on each side of the "main line" near the boundary of your work to which lines are to be measured from each end of it; thus forming two large triangles, one on each side of the base line.

4. On the sides of the triangles already formed, smaller triangles must then be marked out, so as to comprise all the ground to be surveyed.

5. Lines are to be run from any station laid down, or from any part of a line connecting two of them, in directions most convenient for obtaining the fences, taking off-sets to such objects as present themselves, determining the boundaries of rivers, roads, &c.


B
E
C
A
D
780
1010
1412
954
2326
1842
1961
1560
1244
Road to Mitcham
Road to Croydon
RIVER WANDLE
20 Gate
W
E
Scale of 3 chains to an Inch
1000 Links



40 355 to ⊙ C
55 312
54 267
7 0
From ⊙ E
12 780 to ⊙ E
712
15 628
24 373
15 0
From ⊙ B
954 to ⊙ b
854
787 47
637 6
446 53
Road
From ⊙ C
1412 to ⊙ g
1332
1290
River
1223 128
1130 70
978 22
890
⊙ c
700 23
544 84
367 34
From ⊙ E
1560 to ⊙ f
River
1112
1023
861 56
845
Bridge
g ⊙ 824 68
798
684 70
550
437
River
377
70 200
From ⊙ e
547 to ⊙ d
251
62 210
From ⊙ a
1967 to ⊙ B
1474 ⊙ f
River
1176
1115
698
Road
650
From ⊙ D
50 1244 to ⊙ D
54 950
River
Bridge
50 905
700 ⊙ e
40
49 655
65 452
Road
20 275 gate
23 0
From ⊙ A
34 1842 to ⊙ A
5 1440
74 968
953
680 ⊙ d
40 556
80 180
39 0
From ⊙ C
1010 to ⊙ C
Road
971
658
From ⊙ B
2326 to ⊙ B base
1520
1483 ⊙ c
1252
Road
1222
1115 ⊙ b
882
820 ⊙ a
From ⊙ A

The following plate represents a survey, with the field-book from which it was drawn; and, as all the measurements are laid down on the plan with great care, it is hoped that the study of it will sufficiently illustrate the principle of this kind of surveying, as also show that, when the ground is tolerably level, a survey so conducted, if not of too great extent, need not yield in point of accuracy to any other known method.

The field-book entries are in accordance with the instructions already given; the principal of which are, that you begin at the bottom of the page and write upwards, and that the fences and boundaries of rivers, roads, &c., be drawn in the field-book opposite the respective distances, at angles or otherwise, roughly representing the inclinations which they present to the lines measured.

METHOD OF CONDUCTING A SURVEY.

After a careful examination of the ground, the points marked A and B are found to be eligible stations to form the extremities of the base line, as they are not only visible from each other, but staves set up at D and C can also be seen from them both: marks are then set up so as to define a straight line running between A and B, and the measurement is begun at A.*

Measurements on the line, A B.

Starting from the point, A (see plan), the first entry in the field-book will be, at the bottom, " From A." The chaining is then carried on in the direction of B. At 820 links, a point, *a*, appears likely to be useful as a secondary station; a peg is therefore driven at that place and an

* Surveyors now use ranging rods of 8 or 9 feet long, and painted white, for ranging lines.

entry made, as seen in the field-book; encircling it, in order to distinguish it from other points, and putting a letter *(a)* opposite. At 882 links we come to a fence, and are careful to give a slight slant to the short line drawn on each side of the number in the field-book, showing nearly the angle at which it is crossed by the chain. At 1115 we reach a point that will serve us when we come to trace, by means of off-sets, the Mitcham road, as well as to mark a point for a tie or proof-line for the triangle, A B C; a peg is, therefore, driven at that point, the number encircled, and the letter *(b)* placed. At 1222 and 1252, respectively, we cross the boundaries of the road; and at 1483 drive a peg for ⊙ *c*, to facilitate the putting in of an irregular fence running towards E. (Points are thus often fixed, and noted in the field-book, upon the chance of their turning to account when running secondary lines.) The measurement of the line, A B, is found to be 2326 links. Write ⊙ B in the right-hand column, and draw two lines across the centre column to show that the measurement of the base line is complete. Thus the middle column always contains the stations *from*, and the right column those *to*, which measurements are made; as in the field-book before us we see A at the bottom, and ⊙ *a*, *b*, *c*, and B on the right.

Measurements on the line, B C.

The next measurement is from B towards C; the distance measured is 1010 links, crossing a fence at 658, and a boundary of a road at 971 links.

Measurements on the line, C A.

From C it is 39 links to the fence on the left, an entry is therefore made of 39, opposite an 0 in the chain column;

the fence then recedes from the chain line, and at 180 links forms a bend, which is 80 links from the chain, while at 556 it is only 40 links. At 680, fix a station, *d*, to be used afterwards: at 953, cross fence: at 968, the fence has again receded, and is 74 links from the chain; but at 1440, it approaches to within 5 links of it. The whole distance from C to A is 1842, and the fence is there 34 links on the left.

Having thus measured the lines, A B, B C, and C A, we can lay down the triangle, A B C, which embraces nearly one half of the ground to be surveyed. The lines, A D and D B, are now to be measured, that we may be able to construct another triangle, A D B, upon the base line, A B, which then becomes the diagonal of a large quadrangle, A D B C.

Measurements on the line, A D.

The line, A D, skirts a high road; and we have only to take off-sets at every bend of the latter up to its nearest boundary, and also measure the breadth of the road. At A the road is 23 links on the left; 275, there is a gate in the fence, which is 20 links from the chain; 452, a bend, 65 links from chain; 655, the off-set is 49, and the breadth of the road 40; at 700, fix a station, *e*, to be of use for putting in the river, and to serve as a point for a proof-line; at 905, margin of river, over which is a bridge 50 links to the left; 950, opposite bank, with 54 links off-set to bridge. 1244 is the whole distance, and it is 50 links from D to the road.

Measurements on the line, D B.

At 650 and 698 we cross the boundaries of a road; and at 1115 and 1176 those of a river; at 1474 is a convenient point for a station, *f*, forming the tie-line, *e f*, to test the

correctness of the triangle, A D B. The whole line, D B is 1967 links.

We can now construct the two triangles, A B C and A D B, comprising the whole of our ground, except a small triangular portion at its upper end. To obtain this a point, E, is chosen, and the lines, B E and E C, being measured, this little triangle can be formed.

It is quite unnecessary to describe, with the same degree of minuteness, the measurements of the rest of the lines; we shall therefore briefly show the several purposes for which they were run.

The line, e f.

A station was fixed at *e*, while we were measuring on A D, and another at *f*, on D B, for the purpose of planning the river by means of off-sets taken on both sides of a line connecting *e* and *f*; and by reference to the field-book it will be seen that many off-sets were taken. Moreover, if the line, *e f*, when measured on the plan, be found to agree with the distance chained, a proof is afforded of the accuracy of the triangle, A D B.

The line, E *c g.*

Station *c* was fixed, that we might be able to put in a long line of zig-zag fence, running between E and the river. The measurement of a line from E, passing through *c*, enables us to survey this fence with great ease, by means of off-sets.

The line, C *b*, affords the means of surveying a considerable portion of the road running from C to the river, while it at the same time serves as a proof-line for the triangle, A B C.

The line, a d, crosses a fence, and also fixes by means of an off-set of 62 links, the junction point of three fences.

TO CONSTRUCT A PLAN FROM THE FIELD-BOOK.

The rough diagram, which it is always advisable to draw, representing the distribution of the ground into triangles, is now of great service; for it shows us at a glance the situation of the points, C and D, with reference to the base, A B preventing us from running any hazard of forming the main triangles on wrong sides of that line. To construct these, it is only necessary to draw a line on the paper in any convenient direction, and make it 2326 in length, from any scale of equal parts that may be selected; one extremity then represents the point, A, and the other end, B. Take the length of A C, 1842, from the same scale, and describe an arc upon A as a centre, and with the length, B C, 1010, and on B as a centre describe another arc; their point of intersection fixes the point, C. In the same way construct the triangles, A D B and B E C: the next proceeding is to fix, on the main lines, the situations of secondary stations, crossings of fences, and other details. For instance:—

On the line, A B.

Mark the point, *a*, at 820 links, and at 882, the crossing of a fence, drawing a line for a short distance on each side; at 1115, ⊙ *b;* at 1222 and 1252, the boundaries of the road; at 1483, ⊙ *c;* at 1520, a fence.

On the line, C A.

Set off 39 for the off-set on the left at the station; at 180, draw a perpendicular and make it 80; at 556, another perpendicular of 40 links; at 680, mark the point of ⊙ *d;* at 953, a fence crosses the chain line; at 968, a perpendicular of 74 links; at 1440, a perpendicular of 5; and at A, one of 34. Join the ends of these perpendiculars or

off-sets, by a line passing through all the points, and you obtain the run of the fence between C and A.

In the same way go over all the lines measured, uniting the fences, lines of road, &c., wherever it appears evident that a junction must take place, according to the directions in which your lines, crossing the chain lines, are drawn in the field-book.

It must be needless to go into greater detail than has been done already; sufficient information having been given to enable a student of ordinary intelligence, having the plan and field-book before him, to understand this method of surveying. The plan being drawn carefully to a scale of three chains to an inch, and all the off-sets being marked upon it, he can use the scale and compasses when in doubt.

SECTION XVI.

MARQUOIS SCALES AND TRIANGLE — THE PLOTTING SCALE — MATHEMATICAL INSTRUMENTS — OF SCALES — GEOMETRICAL PROBLEMS, AND TRACING FIGURES ON THE GROUND, ETC.

I BELIEVE we are indebted to the late Mr. Landman, of Woolwich Academy, for the earliest publication pointing out the methods of tracing geometrical figures on the ground. I shall only give a few of the most useful problems, which will be chiefly selected from the works of Dalby, Landman, Hutton, and others.

It is as easy to trace geometrical figures *on the ground* as upon paper; there is, however, some difference in the mode of operation, because the instruments are different. A rod or chain is used instead of a scale; the spade instead of a pencil; a cord fastened to two staves and stretched between them, instead of a ruler; the same cord, by fixing one of the staves in the ground, and keeping the other moveable, answers the purpose of a pair of compasses; and with these few instruments, every geometrical figure necessary in practice may be easily traced on the ground. But before we proceed to the ground problems, it will be as well to make mention of such instruments as military men find most useful in laying down or plotting figures and surveys.

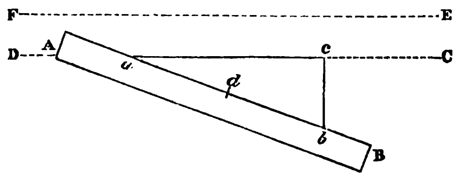
USE OF MARQUOIS SCALES AND TRIANGLE.

The methods of raising and letting fall perpendiculars, forming right angles, drawing parallel lines, &c.,

as shown in the geometrical problems, are only employed by practical men when their plans are upon a very large scale: they commonly use a flat ruler and triangle, by which perpendiculars are formed, and parallel lines drawn, much quicker, and even more accurately.

Many years ago the late Mr. Marquois devised the scales of equal parts to which his name has been attached, which are always accompanied by a triangular ruler. The following brief description will assist the learner in acquiring the use of the scales, with which the students at our military colleges are all familiar.

The triangle is right-angled, and its hypothenuse, or longest side *a b* (see diagram), is exactly three times the length of the shortest. or perpendicular *b c*.



The method of drawing parallel lines by means of one scale or ruler, and the triangle, is thus:—

Suppose that a line is to be drawn through a point, F, parallel to another line, D C; place the triangle so that its edge, *a c*, shall agree with the line, D C; then apply the ruler, A B, to the opposite, or hypothenuse side, *a b;* press it down with the left hand to keep it steady, while with the right you slide the triangle towards A, until the edge, *a c*, touches the point, F; draw a line along this edge, and you obtain the parallel line, F E.

But besides drawing parallel lines, we can draw them at given distances, and more accurately than by measuring off the distances, with a pair of compasses. Each edge of

the rulers is graduated, and marked from the middle, 10, 20, 30, &c., both ways; and below this graduation is another scale which is numbered from left to right, the left division being divided into 10 equal parts, while the others are numbered 1, 2, 3, 4, &c., to a considerable length. Under this second scale, and at the centre, is the number 20, or 25, 30, 35, 40, 45, 50, or 60; which signifies, that so many of the minute divisions at the left hand of the lower or inward scale go to an inch. For instance, take the scale of 20, the first division on the left contains 10 equal parts, and two of them therefore contain 20 of those parts, the measure of which is an inch.

For the sake of distinction, the outer scale, or that at the edge, is termed the *artificial* scale; and the inner, or second, the *natural* scale. The artificial is just three times the size of the natural scale, that is, three of the small divisions of the later make one of the former. Now, the triangular ruler above mentioned has its longest side precisely three times the length of the shortest side; therefore, the artificial and natural scales on the rulers are in the same proportion to each other as the longest and shortest sides of the triangle, viz. 3 to 1. In practice, suppose you are working by the scale of 20, and that you call each of the smallest divisions 10 links, the largest divisions will be then 100 links, and you are using a scale of 200 links to an inch. Again, suppose you wish to draw a line parallel to another in your plan at 10 links distance; to do this, you have only to adjust the thin edge of the triangle to the line, apply your scale of 20, so that the zero line, or centre, agree with the index, *d*, of the triangle (see diagram), and slide the triangle one division, as denoted by the index; when, if a line be drawn along the triangular ruler, it will be just 10 links, or the 20th of an inch from

the former line. For 100 links, slide 10 divisions of the outer scale, and so for any number.

If you are using the outer scale without reference to the inner one, and want to draw parallel lines at given distances, you have only to slide 3 divisions for the distance of one of them measured perpendicularly. Referring to the scale marked 30, 10 of the outer divisions go to an inch, and therefore to draw parallel lines an inch apart, slide 30 divisions. It may be of use to remember, that on the scale marked 60, 10 of the outer divisions make half an inch.

Suppose you wish to draw a line parallel to another at a great distance, upon paper. Place the two rulers side by side, causing the edge of one of them to agree with the given line, you may then move them alternately, advancing them towards the part of your paper at which the intended parallel line is to be drawn, taking care to keep one always firmly pressed down while moving the other. Or, you may lay one of the rulers on the paper and place the short side of the triangle against it, when it is evident that you may draw parallel lines by sliding the triangle up or down.

Lastly, the ruler and triangle are exceedingly useful when a perpendicular straight line is required to be drawn. For instance, if a line be drawn along the edge, *c b* (see diagram), it will be at right angles to D C; and by sliding the triangle to the left or right, all lines drawn along the edge, *c b*, will be equally perpendicular to C D. As the student will constantly want to draw perpendiculars in this way, when constructing the figures of surveys, and laying down off-sets, I recommend him to procure a pair of Marquois scales with the triangle, and to make himself master of the methods of using them.

THE PLOTTING-SCALE.

Surveyors generally use what is called a plotting-scale for measuring off-sets: this is an ivory ruler about 6 inches long, the edges of which are graduated from the centre; and by making a line which crosses the scale to agree with the chain line, the length of each off-set can then be marked off at once. The ivory military protractor or plain-scale, already spoken of, serves as a plotting-scale.

OF MATHEMATICAL INSTRUMENTS.

Surveys cannot be laid down, nor indeed can any figures be accurately constructed, without the aid of a pair of compasses and a scale of equal parts; but these two instruments, with a black-lead pencil, are all that are absolutely necessary. However, as plans ought to be neatly executed, a steel line-drawing pen is wanted; and it is convenient also to have the means of fixing a pencil-leg to the compasses for sweeping arcs of circles, &c. We will therefore allow the student to require,—

1st. A pair of compasses.
2nd. A steel drawing-pen, to fix into a leg of the compasses,
3rd. A pencil-leg to do the same.
4th. An ivory "plain-scale," having engraved upon it two diagonal scales, viz., half and quarter inch, with other scales on the reverse side, while its edges are graduated from 0 to 180 degrees, for laying-off angles.*

* The above are all the instruments really required by a young student in common surveying.

An

OF SCALES.

The divisions used for measuring straight lines, are called *scales of equal parts*, and are of various lengths, for the convenience of delineating any figure of a large or smaller size, according to the fancy or purposes of the draughtsman. They are, indeed, nothing more than a measure in miniature, for laying down, upon paper, any known measure, as chains, yards, feet, &c., each part on the scale answering to one link, one foot, one yard, &c.; and the plan will be larger or smaller, as the scale contains a smaller or greater number of parts in an inch. Hence a variety of scales is useful to lay down lines of any required length, and of a convenient proportion, with reference to the size of the plan.

Scales, of equal parts, are divided into two kinds; the one simply, the other diagonally divided.

Six of the simply divided scales are often placed one above another upon the same ruler; they are each divided into as many equal parts as the length of the ruler will admit of; the number attached to each indicates how many parts to an inch the scale is divided into.

An ordinary case of instruments contains the following:—

1. Large Compasses.
2. Small Ditto.
3. A Drawing-Pen.
4. Bow-Compasses.
5. Steel Pen, to fit large Compasses.
6. Pencil-Leg, for ditto.
7. Pencil-Holder.
8. Ivory Plain-Scale.
9. Parallel Ruler.
10. Sector.

Of these, it is sometimes convenient to have the second size compasses (2), and the drawing-pen (3), in addition to what I have recommended above; but neither bow-compasses (4) nor the pencil-holder (7) are wanted. The diminutive parallel ruler is a useless toy, and nobody uses the sector. A pair of *turn-in* compasses, well known to military men, constitutes a case of instruments sufficient for most military purposes.

The diagonal scale enables us to take off measurements with the utmost accuracy; for any one of the larger divisions (which are half an inch long on a 6-inch ivory ruler, contained in a set of mathematical instruments,) may be subdivided into 100 equal parts; and, therefore, if the scale contain 10 of the larger divisions, any number from 1000 downwards may be taken off with perfect accuracy.

The 6-inch ivory ruler has generally two diagonal scales upon it, namely, the half and quarter inch scales, and the first division of each is subdivided into 10 equal parts: hence, if a large division be taken as 100, the small divisions will be each 10: and the units are obtained by means of 11 parallel lines, making 10 divisions upwards. (For the principle of the construction of a diagonal scale, see problems.)

Let the learner consider well the construction of a diagonal scale, and then try to take off numbers from it.

Example 1. — *To take off* 344. Set one point of the compasses on the place where the third vertical line cuts the fourth horizontal one, and extend the other point to where the fourth diagonal cuts the fourth horizontal line.

Example 2. — *To take off* 523. Set one point of the compasses on the spot where the fifth vertical cuts the third horizontal line, and extend the other point of the compasses to where the second diagonal cuts the third horizontal line.

Example 3. — *To take off 2 chains 22 links.* Set one point of the compass on the place where the second vertical cuts the second horizontal line, and extend the other point to where the second diagonal cuts the second horizontal line.

TRACING FIGURES ON THE GROUND, ETC.

1. *To draw upon the ground a straight line through two given points.*

Plant a picket or staff at each of the given points, then fix another between them in such a manner that, when the eye is placed at the edge of one staff, the edges of the other two may coincide with it. The line may then be prolonged by fixing up other staves. The accuracy of this operation depends greatly on fixing the staves upright, and not letting the eye be too near the staff from whence the observation is made.

2. *To walk in a straight line from a proposed point to a given object.*

Fix upon some point, as a bush or a stone, or any mark that you find to be in a line with your given object, and walk forward, keeping the two objects strictly in line; selecting a fresh mark when you come within 20 or 30 paces of the one upon which you have been moving. Observe that, to walk in a direct line, it is always necessary to have two objects constantly in view.

3. *To trace a line in the direction of two distant points.*

Let two persons separate to about 50 or 60 paces; then by alternately motioning each other to move right or left, they soon get exactly into line with the distant objects; or, for greater accuracy, they may hold up staves.*

In sketching ground, it is constantly necessary to get in line between two objects; if these are not very distant, a well-drilled soldier can always do so within a few paces (near enough for sketching purposes) by fronting one object exactly, and then facing to the right about; when, if he

* One person may perform this operation, but not so quickly.

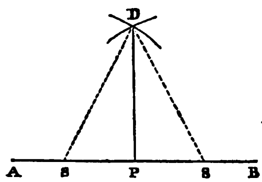
finds himself accurately fronting the other object, he will be tolerably well in line with them.

A right angle may also be formed very nearly by fronting an object, and then facing to the *right* or *left*.*

I have found such little expedients very useful in practice, or I should not have ventured to mention them here, as some might consider them puerile.

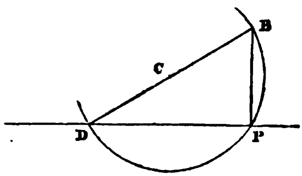
4. *At a given point*, P, *in a right line*, A B, *to raise a perpendicular*, P D, *to that line.*

On each side of P take equal distances, P S, P S, and about S S, as centres, with the same radius, describe arcs intersecting each other at D; then draw P D for the perpendicular required.



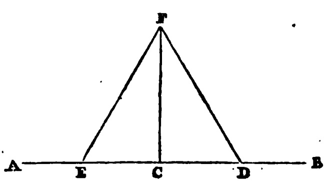
5. *When the given point*, P, *is near the end of the line.*

About any convenient point, C, as a centre, describe a circle through P, cutting the given line in D, draw D C B, then join B P, which will be the perpendicular required.



6. *To raise a perpendicular from a point*, C, *to the given line*, A B, *on the ground.*

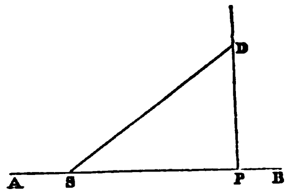
Set off two points, E and D, equally distant from C; double a cord into two equal parts, and fasten the ends at E and D; take the middle of the cord in the direction of



* See Optical Square.

F, and draw tight; then will C F be the required perpendicular.

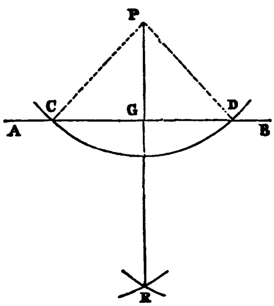
7. A perpendicular is easily raised on a given line, and consequently a right angle formed by means of the numbers 3, 4, and 5, or any multiples thereof. Thus, suppose a right angle is to be formed at the point, P, on the line, A B; take S P = 16, P D = 12, and S D = 20 feet; then P D will be perpendicular to A B.



The pocket sextant and optical square offer the most accurate and expeditious method of raising or letting fall a perpendicular.

8. *From a given point,* P, *to let fall a perpendiculr,* P G, *upon a given line,* A B.

About P, as a centre, with any radius, P D, greater than the distance of P from A B, describe an arc, D C; and from D and C, with a radius greater than half D C, describe arcs intersecting each other in R: join P R; then P G is the perpendicular required.



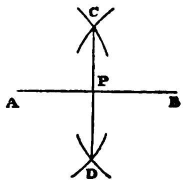
9. *To draw a line parallel to a given line on the ground.*

Raise two perpendiculars to the given line, and upon these set off equal distances; join the points, and the parallel line will be obtained.

A similar process will answer on paper; but a parallel ruler, or a small flat ruler, together with one of a trian-

gular form, which has already been described at p. 140, saves us the trouble.

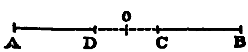
10. *To bisect, or divide into two equal parts, a given line,* A B.



With any opening of the compasses greater than half the given line, about the extremities, A and B, as centres, describe arcs intersecting each other in C and D; then draw C D, and it will bisect A B in the point, P.

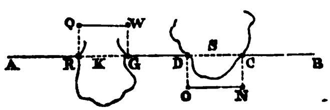
In this manner a line may be divided into 4, 8, 16, &c., equal parts;—thus, A P, B P, bisected, give 4 equal parts: and those again bisected would give 8; and so on.

11. The most expeditious method of finding the middle of a line on the ground is to measure equal distances from its extremities. Thus, suppose A and B are the line, and that A D, B C (found by measuring from A to B, are each 164 feet; and the remaining part, D C, is 20 feet; then O, the middle of the line, will evidently be 10 feet from D or C.



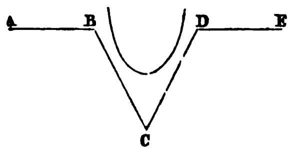
12. In measuring lines or distances on the ground it sometimes may be necessary to take off-sets when obstacles fall in the way.

Suppose A and B are the extremities of a line to be measured; and that K and S are pools of water or swamps. Having set up marks at R, G, D, C, in the line A B, measure equal off-sets, C N., D O; and G W, R Q, at



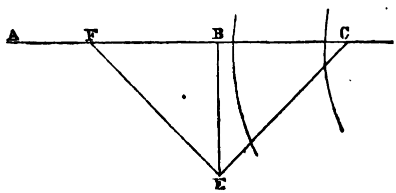
right angles to A B; then Q W and O N may be measured. instead of R G and D C.

Perhaps a more convenient method is to measure on a line, making an angle of 60°, with the original direction, a distance sufficient to clear the obstacle, and to return to the line at the same angle; the distance, B D, is then equal to either of these measured lines.

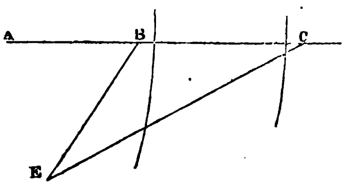


13. *To measure across a river.*

On the line, A B, take a point, F, making F B greater than the breadth of the river; set up a mark at E, forming a right angle at the point, B, and make B E about equal to F B: then; with any instrument for taking angles, make the angle, B E C, equal to B E F. Place a mark at C, in line with A B, and B C will be equal to F B.*

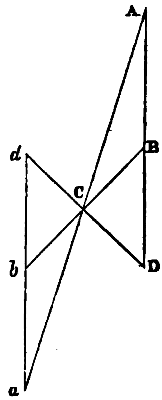


Or, make B E to form any convenient angle with A B, and make the angle, B E C, equal to half the angle, ABE; then a mark being set up at C, in the prolongation of A B, it is evident that B C will be equal to B E.



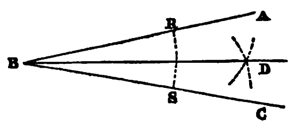
* See method of measuring inaccessible distances by means of a pocket-sextant.

14. *To find the distance to any accessible point without an instrument for measuring angles.*



A is any inaccessible point whose distance from B is sought. Produce A B, to any point, D, draw D *d*, in any direction, and find C, the point bisecting it; join B C, and produce it to *b*, C *b* being equal to B C; join *d b*, and produce that line to *a*, meeting A C prolonged; then *a b* = A B and *a d* = A D.

15. *To bisect a given right-lined angle,* A B C.

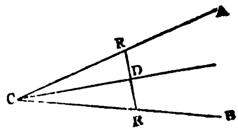


With any convenient radius, B S, about the angular point, B, as a centre, describe an arc, S R; and from the centres, S R, with any radius longer than half the distance between those points, describe two other arcs, intersecting one another in D; then the line joining B and D will bisect the angle, A B C, and the arc, S R.

By such bisections an angle, or its corresponding arc, may be divided into 2, 4, 8, &c., equal parts. A quadrant, or an angle of 90°, may thus be divided or subdivided, until each arc subtends an angle of only a few minutes. Such a division is readily performed if the radius is 5 or 6 inches; and will be found convenient for measuring the degrees of an angle, when the usual instruments for that purpose are not at hand.

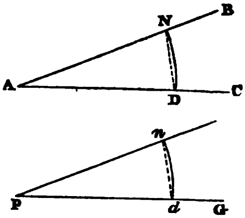
16. *To bisect an angle*, ACB, *on the ground.*

Measure equal distances, C R, C R, from the angular point, C; then D, the middle of the cross distance, R R, gives the direction of the line, C D, which bisects the angle.



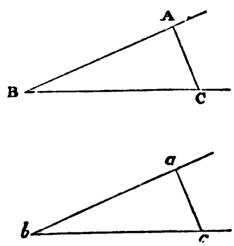
17. *At a given point*, P, *in a right line*, P G, *to make an angle*, nPG, *equal to a given right-lined angle*, B A C.

About A and P, with the same radius, describe arcs, D N and $d\,n$; take $d\,n$ equal to D N, and draw Pn; then the angle, n P d, is equal to the angle, N A D or B A C.



18. *On the ground.*

Set off any number of equal parts from B to C, and from B to A, and with the same parts measure A C; describe on the ground with these three lengths a triangle, *a b c*, and the angle, *a b c*, will be equal to the angle, A B C.

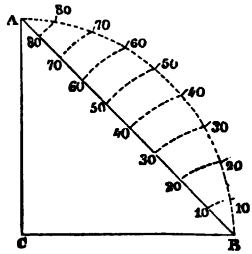


When it is proposed to make an angle which shall contain a given number of degrees, &c., a *protractor*, or *line of chords*, will be necessary.

The common protractor is a semicircular instrument for measuring and laying down angles. The arc or limb is divided into 180 equal parts or degrees; and when its centre is placed over the intersection of two lines, the number of degrees in the angle is shown by the intercepted arc on the divided edge of the instrument. A protractor for the same purpose is frequently cut on the common plain

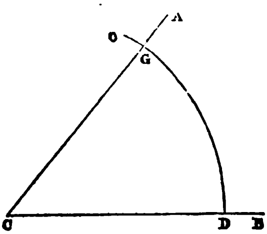
scales, the centre being on one edge and the graduations on the other. This is the ivory protractor mentioned at page 7.

A line of chords is made by transferring the divisions on the arc of a quadrant to its chord. Thus, suppose A C B is a quadrant, and the right line, B A, the chord of its arc. Let this arc be divided into 90 equal parts or degrees: then, if one foot of a pair of compasses be kept on the point, B, and arcs successively described with the other from each of the 90 divisions on the arc to meet B A, those arcs will divide it into a line of chords.



19. *To measure an angle with the line of chords.*

Suppose the angle, A C B: with the radius, C D, equal to the extent of 60 degrees on the line of chords,* about the angular point, C, as a centre, describe the arc, D G; then the extent from D to G measured on the line of chords, gives the number of degrees, &c., contained in the angle: which in this example is about 51 degrees.



Hence the method of laying down an angle which shall contain a proposed number of degrees, is obvious. Suppose, for example, it is required to make the angle, A C B, of 40 degrees: C B being a given line. With C D, the chord of 60 degrees, describe an arc, D O, as before; then 40 degrees, taken on the same line of chords, will extend from D to the point, G, in the arc, through which the line, C A, must be drawn, to form the required angle.

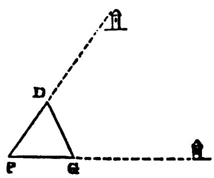
* Sixty degrees are taken for the radius, because the chord of 60° is equal to the radius.

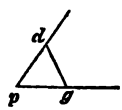
When the angles are greater than 90 degrees, measure or lay them off at twice. Or produce one side, so as to form two angles at the angular point, and then measure the supplement to 180 degrees.

A line of chords is usually marked on the plain scale, furnished in a case of mathematical instruments.

20. *To determine nearly the angle formed by a point, and two distant objects.*

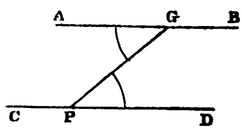
To ascertain the angle, D P G, formed by two distant objects and an angular point, P, measure equal distances, P D, P G, and the cross distance, D G; then construct a triangle, *d p g*, on paper, similar to DPG, and measure the angle, *p*, with a protractor or the chords. Thus, if PD, P G, are each 30 feet, and D G = 28½ feet, the triangle, *dpg*, constructed with 30, 30, 28½ equal parts from any scale, will give the angle, *p* (or P), = 56¾ degrees nearly.



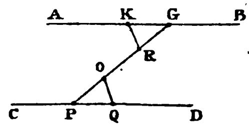


21. *Through a given point,* P, *to draw a line,* C D, *parallel to a given line,* A B.

From P draw P G, in any direction to meet the given line, A B; then make the angle, GPD, equal to the angle, A G P (17); and P D will be parallel to A B: because the alternate angles, A G P, G P D, are equal.



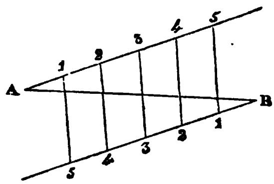
22. *To trace the parallel,* C D, *on the ground.*



Fix upon any convenient point, G in A B, and measure an isosceles triangle, R G K: then, at the point, P, lay down the triangle, O P Q, equal to R G K; and P Q will be parallel to G K.

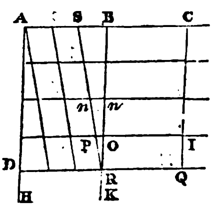
23. *To divide a given line,* A B, *into a proposed number of equal parts; suppose six.*

From the extremities, A and B, draw two lines, parallel to each other, forming any convenient angle with A B; on these lines set off five equal parts, of any length; join the opposite points of division; and A B will be divided into six equal parts.



24. Diagonal scales, which are constantly used, are thus constructed. Suppose a scale to 12ths of a line, A B, is required.

Having divided A B into three equal parts, draw two parallel lines, A H, B K, making any convenient angle with A B; on these lines take four equal distances, suppose from A to D and from B to R; and through the points of division draw four lines, parallel to A B; next divide D R into three equal parts; then, if the points of division, in A B and D R, are joined diagonally, the scale is constructed.

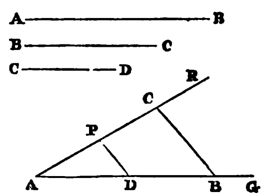


For by similar triangles, R B : B S :: R O : O P; therefore, R O being $\frac{1}{4}$ of R B, O P will be $\frac{1}{4}$ of B S, or $\frac{1}{4}$ of $\frac{1}{3}$ (or $\frac{1}{12}$) of B A; and the next division, *n n*, is $\frac{2}{12}$, &c.

If Q R = C B = B A is the scale of a *foot*, O P is an *inch*, *n n* = 2 inches, I P = 13 *inches*, &c. But if we divide A B into 4 equal parts, only 3 must be taken on A A and B K to make 12ths of A B (because 4 × 3 = 12.)

Generally, resolve the number to which the divisions are to be extended into two factors; then divide the given line (A B) into as many equal parts as there are units in one factor, and take as many equal parts on the other lines (A H, B K) as there are units in the other. Thus, if A B is divided into 3 equal parts, and 5 are taken on A H, B K; or if A B is divided into 5, and 3 are taken on A H, B H, in either case the scale gives 15ths of A B. On the common plain scales with mathematical instruments the equal parts on each line are 10, which give the divisions in 100ths.

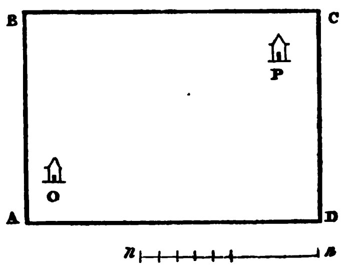
25. *To find a fourth proportional to three given lines,* A B, B C, C D.



Draw two lines, A G, A R, forming any convenient angle at A, make A B = A B, A C = B C, and join B C; then take A D = C D, and draw D P parallel to B C. By similar triangles, A B : A C :: A D : A P, the 4th proportional required.

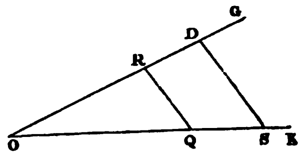
26. This Problem is of very extensive use in the reduction of scales, plans, and maps. We shall subjoin examples.

If A B C D be the plan of a country, and suppose the distance between the objects, O, P, is 1700 paces of a horse, at $2\frac{3}{4}$ feet each; it is required to make a scale of yards to the plan.



$$\frac{2\frac{3}{4} \times 1700}{3} = 1558 \text{ yards.}$$

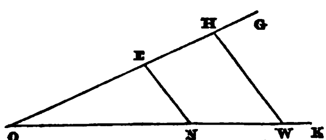
Having drawn two indefinite lines, O K, O G, forming any angle at O, make O S equal to the distance, O P; and from any scale of equal parts, set off O D = 1558, and O R = 1000; join D S, and parallel to it draw R Q, then O Q is a scale of 1000 *yards*. This divided and subdivided is the scale, *n n*, in which each of the least divisions is 100 *yards*.

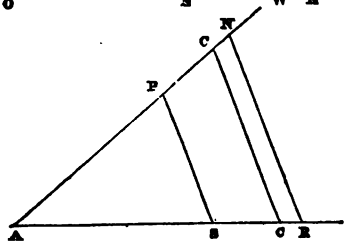


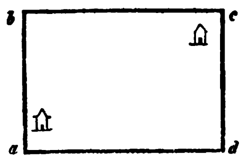
Or, without the construction, thus: the distance, OP, measured on a scale is 1·53 *inches*. Then, as 1558 : 1·53 : : 1000 : 0·98 *of an inch*, the length of *n n*, the scale of 1000 *yards*.

27. Let the plan in the last example be reduced to a scale of 1 *inch to a mile*.

On the indefinite lines, O K, O G (as in the last example), set off O E = 1000, and O H = 1760 (the yards in a mile) from any convenient scale of equal parts; and make ON = the scale, *nn;* join E N, and parallel to it draw HW; then O W is the scale of a mile to the plan, A B C D.





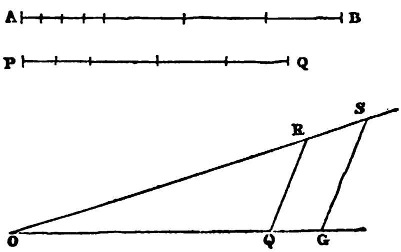


Now, with A C = O W, and C C = 1 *inch* (the two scales) make the isosceles triangle, ACC; then because any two corresponding distances on the plan must be in the same proportion as the two scales, if A R be made equal to the length of the plan, A B C D, and A S = A B its breadth, R N and S P (which are parallel to C C) will be the length and breadth of the reduced plan, *a b c d*.

28. Suppose a map is laid down to the scale, A B, of 4000 *toises*; and let it be required to adapt a scale (P K) of *English miles* (4 for example) of the same map.

The toise is = 2·1315 yards. Therefore

$$\frac{2{\cdot}1315 + 4000}{1760} = 4{\cdot}84 \textit{ miles} \text{ nearly, the scale, A B.}$$



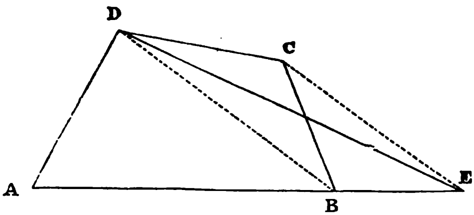
On two indefinite lines, O S, O G, making any angle at O, set off O S = 4·84, and O R = 4, from any convenient scale of equal parts; make O G = the scale, A B; join S G, and draw R Q parallel thereto; then Q O (P Q) is a scale of 4 miles.

Or thus:—The length of the scale, A B, is 1·73 *inches:* therefore, as 4·84 *m.* : 1·73 *in.* :: 4*m.* : 1·43 *in.*, the length of the 4 mile square, P Q.

And the map, or any part of it, may be enlarged or diminished to a proposed scale, after the manner seen in 26: for we can suppose A B C D to be a given part of a large plan.

29. *To reduce a given trapezium,* A B C D, *to a triangle of equal area.*

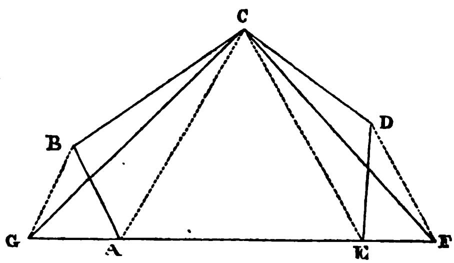
Draw the diagonal, D B, and parallel to it draw C E, meeting A B produced in E. Join the points, D E; so shall



the triangle, A D E, be equal to the trapezium, A B C D; for the triangle, D B E, is equal to the triangle, D C B, having the same base and altitude.

30. *To reduce an irregular polygon,* A B C D E, *of five sides, to a triangle of equal area.*

Extend the side, A E, both ways at pleasure; and draw the diagonals, C E, C A. Parallel to these diagonals draw

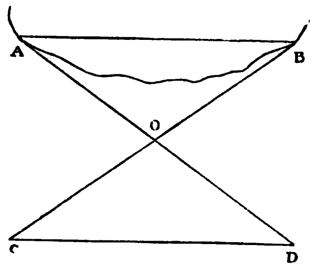


the lines, D F and B G; join the points, C F, C G; and G C F will be the triangle required.

Note.—This and the former problem may be applied in finding the areas of trapeziums and irregular polygons, by first reducing them to triangles.

31. *To find the length of the line,* A B, *accessible only at both ends.*

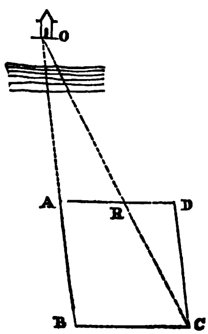
Having fixed on some convenient point, O, measure B O and A O; and prolong those lines till O C = O B, and O D = O A; then the distance between the points, D and C, will be equal to A B.



For the sides of the triangles, C O D, B O A, about the equal angles at O are respectively equal, therefore the third sides, C D, B A, will also be equal.

32. *To find the distance of an inaccessible object,* O, *by means of a rhombus.*

With a line or measuring-tape, whose length is equal to the side of the intended rhombus, lay down one side, B A, in the direction, B O, and let B C, another side, be in any convenient direction; fasten two ends of two of those lines at C and A; then the other ends (at D) being kept together, and the lines stretched on the ground, those lines A D, C D, will form the other two sides of the rhombus. Set up a mark at R, where O C, A D intersect; and measure R D; then the sides of the

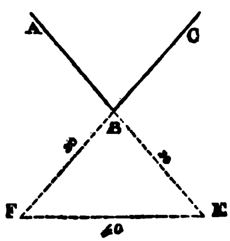


triangles, R D C, C B O, being respectively parallel, the triangles will be similar: hence, R D : D C :: C B : B O.*

Suppose the side of the rhombus is 100 feet, and R D = 11 *ft.* 7*in.*—then, $11\frac{7}{12} : 100 :: 100 : 863$ *feet nearly* = B O.

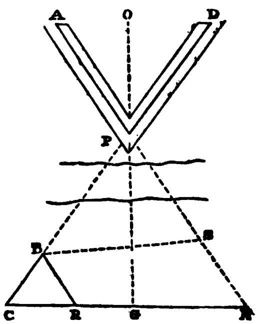
If the ground be nearly level, a rhombus, whose side is 100 feet, will determine distances to the extent of 300 yards within a very few feet of the truth.

33. *To measure from the outside an angle,* A B C, *formed by two walls,* A B, C B.



Lay off 30 feet from B to E in the direction, A B, and plant a staff at E; set off the same measure from B to F in the direction, B C, and measure F E, and you may obtain the measure of your angle, either by laying it down on paper, or by calculation.

34. *To bisect an inaccessible angle.*



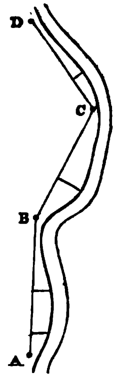
Let it be required to determine the direction of the capital, O P, of a bastion. At any points, B, S, in the direction of the faces, D P, A P, set up two marks; and from B trace B R, parallel to P S; measure equal distances, BC, BR, and mark the point, K, in the direction, C R; then find G, the middle of C K; and the prolongation of G P will bisect the angle A P D.

Hence, if we measure C B, C R, C K, the distances, C P, K P, are found by similar triangles. For C R : C B ::

* An easy method of finding the distance of an inaccessible object, as an enemy's battery, &c., is by means of a pocket-sextant. See page 95.

C K : C P., and a perpendicular from B on C R will give distance, G P, at another proportion.

35. *To obtain the plan of a river.*

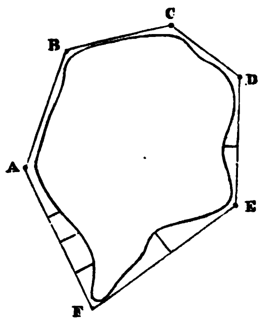


Place marks at its principal bends, A, B, C, D, and with a surveying compass take the bearings of the station-lines, A B, B C, D C, &c.; and when measuring these lines take off-sets to all the smaller bends, as shown in the diagram.

The plan may be either protracted in the field, or the bearings and measurements entered in a field-book.

See also traversing with the theodolite, which is applicable to this, as well as the two following problems.

36. *To take the plan of a wood, a lake, or marsh. &c.*

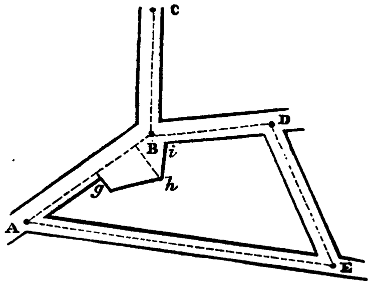


Place marks, A, B, C, &c., so as to form the most convenient station-lines, A B, B C, &c., all round the wood or marsh; then with a surveying compass take the bearings of A B, B C, C D, &c., going all round measuring and taking off-sets as you proceed. If the survey be of a marsh or lake, *check* bearings should be taken across it, as from A and B to D, &c,; which will ensure greater accuracy, and cause the work to close (as it is termed, with proper exactness.

The method recommended in Section II., of surveying and protracting, so as at once to obtain a plan, is well suited to objects of this kind.

37. *To take the plan of a town.*

This is done precisely in the manner pointed out in Section VII., for surveying a road. Thus, suppose the annexed diagram to represent a town, and the point, A, from which we can look down two streets, A B and A E, is selected for commencing the survey. We will suppose a prismatic compass and chain to be used. First take the bearing of B, then that of E; measure A B, taking the necessary off-sets for the width of the street. The points, *g*, *h*, *i*, where the street opens into a wide space, are also determined by off-sets taken perpendicularly to the chain line. At B the bearings of B C and B D are taken, and their distances measured. At D take the bearing of E, when, if the length of the line, A E, on the survey, being laid down or protracted, agrees with the measured distance, a proof is afforded that the work is accurate.

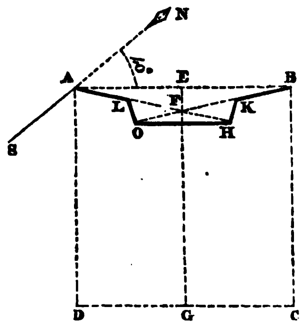


In general, bandrols or staves, for marking station-points, may be dispensed with, as corners of streets, door-posts, &c., afford sufficient marks.

38. *To trace out a field-work with the aid of a surveying compass.*

We will suppose the required field-work to be a square-bastioned fort. Having fixed the direction of one exterior side, A B, mark its length, say 200 yards, and trace the square, ABCD; thus, at A take the bearing of B, which we will suppose to be 40° E., the angle, N A B (N S representing the magnetic needle). Add 90°, and we have 130°

E, for the direction, A D, of a line, at right angles with A B. Cause an assistant to hold a staff nearly in the required direction, A D, which he is to move by signal until his staff is found to bear exactly 130° E; it is then to be fixed in the ground. Proceed to B, and by the same process plant a staff



which shall bear 130° S.E., the direction of C; make A D and B C each equal to A B. and the four points of the square are determined.*

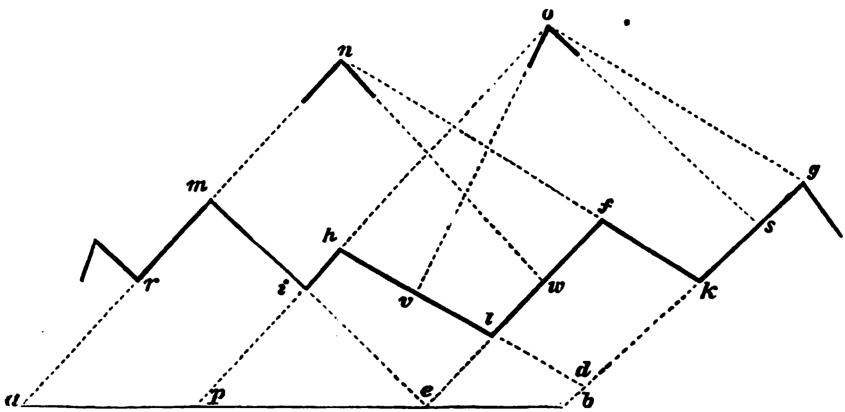
Next bisect A B and C D, and the direction, E F, of the *perpendicular* is obtained. Take E F, equal to $\frac{1}{8}$ of A B (the usual proportion to a square), and the *lines of defence,* A H and O B, are then easily traced. On these lay off A L and B K, equal to the proposed length for the faces of the *bastions;* and from L and K let fall perpendiculars to A H and B O, respectively, for the *flanks;* join O H, the *curtain,* and one *front* of the work is traced.

39. *To survey intrenchments and field-works.*

The diagram in next page represents an irregular line of intrenchment, with two advanced *flèches;* of which we will suppose a plan is required.

Measure a base, *a b,* having its extremities on the prolongations of two lines of the works, when convenient; thus *b* is on the prolongation of *g k,* and *a* upon that of *m r.* Set up marks at *a* and *b,* as also at such of the angles of the intrenchment as may not be sufficiently defined for observations. Draw a line on your paper, and lay off the

* The pocket-sextant and optical square are the best instruments for laying out a work of this kind.



length of the base; having done which, place yourself at *b*, and measure the angle, *a b g*; protract this angle. Next measure from *b* towards *k*, noting the distance of *d* (prolongation of *h l*); then fix *k*, and measure on to *g*, marking the point, *s*; observe the angle, *g k f*, which lay down. Now return to *b*, and measure to *e* (prolongation of *f l*); observe the angle, *l e b*, and fix the point, *l*, by measurement from *e*; join *d l*, of which *l h* is a continuation; then measure on to *f*, and join *f k*. Next measure from *e* to *p*, along the base line, and observe the angle, *i p e*, and measure from *p* to *i* and *h*; join *e i*, and continue the line towards *m*. Measure from *p* to *a*, observe the angle *r a p*, and find the points *r* and *m*. Thus far no notice has been taken of the *flèches*; but, while at *g*, the angle, *k g o*, should have been observed, and the prolongation of *i h*, intersecting *g o*, fixes the point *o*. The directions of the faces of this *flèche* are determined by *v* and *s*. For the *flèche*, *n*, its salient is determined by an angle taken at *f*, intersecting the prolongation of *r m*, while the right face falls on *l f* at *w*. We have, lastly, only to ascertain the lengths of the faces of these two advanced works, and the task is complete.

Either the sextant or compass may be used for taking the angles, but if the ground is tolerably level, the former instrument will give them most correctly. The linear measurement should be performed with a chain and measuring tape, or, if these are not at hand, a rope may be used. Pacing is not suited to such an operation, and can only be admissible when other means cannot be employed.

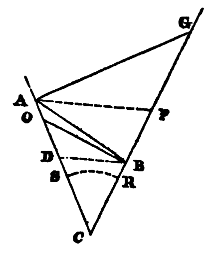
A plan of any military work requires to be accompanied by profiles, or cross vertical sections, showing the height and thickness of its parapets and ramparts, width, and depth of the ditches, steepness of the slopes of the work, &c.; but this part of the business belongs to *levelling*, and will be found in its proper place. [See *Levelling*.]

SECTION XVII.

APPLICATION OF TRIGONOMETRY TO MEASURING HEIGHTS AND DISTANCES — REDUCTION OF OBLIQUE ANGLES, TAKEN WITH A SEXTANT, TO THE CORRESPONDING HORIZONTAL ANGLES—PORTABLE TRIGONOMETRY.

THE instrument proper for measuring horizontal and vertical angles, in common trigonometrical operations, is a theodolite; but, after all the care that may have been bestowed in correcting the line of collimation, telescope level, &c., it seldom happens that the elevations or depressions shown by the instrument are correct. It is, therefore, always advisable to determine the *error*, or how much the elevations or depressions are too great or too little. This may be done in the following manner:—

Let C be the centre of the earth, S R an arc on its surface, A the place of the telescope when the theodolite stands in the vertical line C A, B the place of the telescope when it stands in the vertical line C B, A G (perpendicular to A C) the horizontal line at A drawn to meet C G, and B O (at right angles to B C) the horizontal line at B.



Then, if the telescope at B be directed to a mark or object at A, the elevation of that object above the horizontal line, B O, is the angle, O B A; and when the telescope is at A, and directed to an object at B, its depression below the horizon, A G, will be the angle, G A B.*

* These problems from Dalby's Mathematics.

Let S D=R B, and R P=S A. Then because the triangles, A P C, D B C, are isosceles, and the angles, C A G, C B O, right ones, the angle C A P+angle P A G =a right angle; but the angle C A P+half the angle A C P, also make a right angle; therefore, the angle, P A G, or its equal, D B O, is equal to half the angle, C.

Now, the depression or angle, G A B=G A P+P A B (or A B D); or G A B=P A G+D B O+O B A; but P A G +D B O=angle C. Therefore the depression, G A B= angle C+*elev.* O B A; or *depr.* G A B+*elev.* O B A= angle C+twice the *elev.* O B A. Therefore the elevation and depression together, lessened by the angle, C, is equal to twice the elevation; consequently, *half the difference between the sum of the elevation and depression, and the angle*, C, *is the elevation.*

Now, whatever be the error in elevation or depression, their *sum* will be constant; for one is always diminished by the same quantity that the other is augmented: hence the preceding rule gives the *true elevation*, except the angle, C, be greater than the elevation or depression together, in which case the said *half difference* is the *true depression* of the highest of the two points or objects, A B.

And when the observations are both elevations, or both depressions, their *difference* is constant, and *half the difference between the angle*, C, *and that constant difference, will be the true elevation of the highest of the two points*, A, B, *if the angle*, C, *be the less, but equal to the true depression of that highest point or object when it is the greater.*

Should both the reciprocal observations be depressions (or both elevations), and equal to each other, the vertical heights, S A and R B, are equal; and the true depressions will be half the angle, C.

Example.

The following observations were made with a theodolite, for determining the error in the vertical angles taken with that instrument.

Two marks, A and B, were set up exactly at the same height above the ground as the height of the telescope; and at A the depression of B, or the angle, G A B, was 24′; and at B the elevation of A, or the angle, O B A, = 12′. The distance of the stations or arc, S R, was 2600 yards, which, allowing $69\frac{1}{8}$ miles to a degree, gives 1′·28 of a degree nearly, the angle, C.

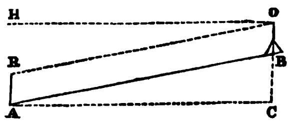
Then, $\frac{24' + 12' - 1' \cdot 28}{2} = 17' \cdot 36$, or about $17\frac{1}{4}'$, the true elevation or angle, O B A; consequently, $17\frac{1}{4}'$—12 $= 5\frac{1}{4}'$ is the *error*, or what the altitudes shown by the instrument were too little, or the depressions too great.

A distance of 600 or 700 yards, however, is sufficient for trying a common theodolite; in which case the angle, C, may be neglected, and the verticals, S A and R B, considered as parallels: the expressions then become more simple. Thus, if one observation be an elevation = 17′, and the other a depression = 13′, then *half their sum* = 15′ is the true elevation or depression; and 17′—15′ = 2′ is what the instrument gives elevations too great. If both are elevations or both depressions, *half the difference* is the true elevation of one station and the true depression of the other.

A base for trigonometrical operations is sometimes measured on sloping ground; it must then be reduced to the corresponding horizontal line, if horizontal angles at its extremities are taken with a theodolite.

Suppose A B is a base of 300 yards, O B a theodolite, and let the height of the staff, A R, be equal to O B, the

height of the instrument; also suppose H O R, the angle of depression of the top, R, below the horizontal line, H O, is 5°; then, if O C is perpendicular to H O, the line, A C, parallel to H O, will be the horizontal base, corresponding to the measured base, A B.



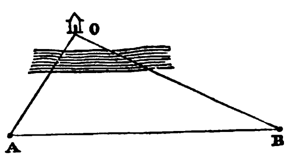
Now, the angles, H O R, B A C, being equal, we have,

As radius	log.	10·000000
To A B 300	log.	2·477121
So is *cosine* of 5° (angle, B A C)	log.	9·998344
To A C, 298·9	log.	2·475465

The difference of A B and A C is only 1·1 yards. Therefore a reduction of this kind seems unnecessary when the measured base is inclined to the horizon in a small angle, except the operation is intended to produce a very accurate result.

To find the distances, A O, B O, *from the stations,* A *and* B, *to the inaccessible object,* O.

A base, A B, was measured of 730 feet, the ground being nearly level; and having set up marks at A and B, the horizontal angles at those stations, taken with the theodolite,



were $\begin{cases} A = 57^\circ\ 12' \\ B = 24\ \ 45, \end{cases}$ whence the distances, A O, B O, are required.

The angle at O, or supplement of the angles, A and B, is 98° 3′. And the *calculation* will be,

As sine angle, O, 98° 3′ . .	log.	9·995699	
		0·004301	arith. comp.
To A B, 730	log.	2·863323	
So is sine of angle A, 57° 12′	log.	9·924572	
To B O, 619·7 feet . . .	log.	2·792196	

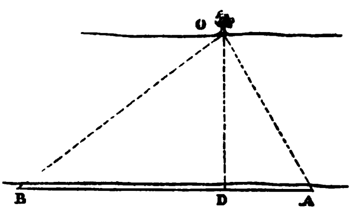
And,

As sine of angle, O, 98° 3′ .	log.	9·995699	
		0·004301	arith. comp.
To A B, 730	log.	2·863323	
So is sine of angle B, 24° 45′	log.	9·621861	
To A O, 308·6 feet . . .	log.	2·489485	

By *construction.*—Take A B=730 from any convenient scale of equal parts; and, by means of a *protractor,* make the angle at A=57° 12′, and the angle at B=24° 45′: then the distances, A O and B O, may be measured by the same scale from which A B was taken.

Wanting to know the breadth (D O) *of a river.*

A base, A B, of 400 yards was measured along the bank, and at the extremities, A and B, angles were taken to an object, O, on the opposite side.



Namely, {Angle O B A=37° 40′ / Angle O A B=59 15. Hence the breadth, O D, is required.

Calculation:—

As *sine* of the angle B O A, 83° 5′ (the supplement of the angles, B and A)	log.	9·996828
		0·003172 arith.comp.
Is to B A, 400	log.	2·602060
So is the *sine* of angle B, 37° 40′,	log.	9·786089
To A O	log.	2·391321

Then,

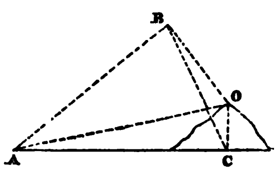
As *sine* of angle, O D A, 90°	log.	10·000000
Is to A O	log.	2·391321
So is *sine* of angle, A, 59° 15′	log.	9·934199
To O D, 211·6 yards	log.	2·325520

Or O D may be ascertained by *construction*. Make B A =400 from a scale of equal parts; and at the extremities, B and A, lay down the respective angles 37° 40′ and 59° 15′; then the perpendicular, O D, upon the base, B A, will be the breadth required. And its measure is 212 nearly.

Wanting to know the distance (A C) *of a hill from the station,* A, *and also the height* (O C).

A base, A B, of 298 yards was measured on ground nearly horizontal, and at the extremities, A and B, we observed the horizontal angles, B A O (or B A C) =42° 17′, A B O (or A B C)=79° 29′; and at A, the angle of elevation, O A C, was 4° 51′. Required the distance, A C, and height, C O.

Method of construction.—The three points, A, B, C, being supposed in a plane parallel to the horizon, and the plane of the instrument at A and B in that plane,



the angles taken to the point O, in the perpendicular, C O, will be the same as they would be if the telescope was directed to the point, C, because the horizontal circle of the theodolite is not moved by elevating or depressing the telescope. Therefore, having made A B = 298, and the angle, B A C = 42° 17′, A B C = 79° 29′, and O A C = 4° 51′, raise the perpendicular, C O; then A C is the distance, and C O the height, sought.

Calculation.—The angle, A C B, is 58° 14′, the supplement of the horizontal angles at A and B.

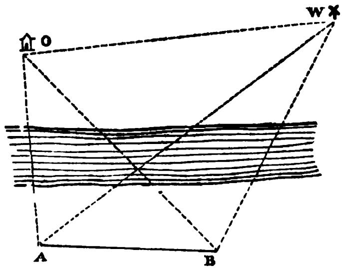
As *sine* of 58° 14′	log.	9·929521
		0·070479 arith. comp.
Is to A B, 298	log.	2·474216
So is *sine* of A B C, 79° 29′ .	log.	9·992643
To A C, 344·6	log.	2.537338
And for the height, C O,		
As radius	log.	10·000000
Is to *tangent* of angle O A C.	log.	8·928658
So is A C, 344·6	log.	2·537338
To C O = 29·2	log.	1·465996

To find the horizontal distance between the inaccessible objects, O W.

A base, A B, of 670 yards, was measured on ground nearly horizontal; and at the extremities, A and B, the following angles were taken:—

At A, $\begin{cases} \text{B A W} = 40° \ 16' \\ \text{W A O} = 57 \ \ 40 \end{cases}$ At B, $\begin{cases} \text{A B O} = 42° \ 22' \\ \text{O B W} = 71 \ \ \ 7 \end{cases}$

By *construction.*—From any convenient scale of equal parts, make A B = 670, and lay down the respective horizontal angles at A and B; join O W, the points of meeting of the lines from A and B; and O W, measured on the scale from which A B was taken, will be 1170 yards nearly, the *horizontal* distance between the objects.



By *calculation:*—

The angles of the triangle, AOB, are $\begin{cases} ABO = 42° \; 22' \\ OAB = 97 \;\; 56 \\ AOB = 39 \;\; 42 \end{cases}$

Whence A O will be found = 706·8 yards.

And the angles of the triangle AWB are $\begin{cases} BAW = \;\; 40°16' \\ ABW = 113 \;\; 29 \\ AWB = \;\; 26 \;\; 15 \end{cases}$

Will give A W = 1389·4 yards.

Now in the triangle O A W we have $\begin{cases} AW = 1389{\cdot}4 \\ AO = \;\; 706{\cdot}8 \end{cases}$

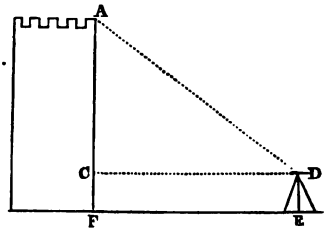
And the included angle O A W = 57° 40′

To find O W.

The distances, both by construction and calculation, are the horizontal ones.

Should O and W be objects elevated, as the tops of hills, their altitude may also be found by observing the respective angles of elevation from the stations A and B.

To ascertain the height of a building.



Measure a line, F E, from the foot of the building, so that the angle, C D A, may be neither too acute nor obtuse; thus, suppose E F = 130 feet, place your theodolite or sextant at D, and measure the angle, A D C = 34° 56′.

Then, as radius is to tangent 34° 56′, so is D C = E F = 130 feet to A C.

Which, by working the proportion, is found to be 90·8 feet, or 90 feet 9·6 inches, to which adding 4 feet for D E, or its equal, C F (height of the instrument), the whole height is found to be 94 feet 9·6 inches.

Should the foot of a building be inaccessible, owing to the presence of a ditch or other obstacle, a base F G, must be measured (see the fig., page 95), and two angles of elevation taken, viz., A C E and A D E; then in the triangle, A C D, one side, D C, and the angles are given to find C A; by means of which, and the angles of the triangle, A C E, the height, E A, is obtained, to which C G = E B the height of the instrument is to be added.

Observe.—That the ground upon which the base is measured must be level, if an accurate result be expected.

To find the height and the distance of the object, O, *on the top of a hill from the station,* B.

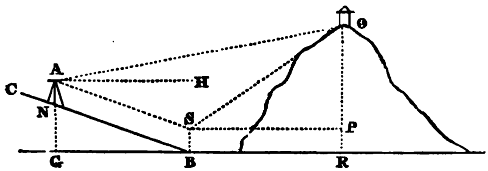
We measured a base, B N, of 642 yards, up the sloping ground, B C, directly from the object, O, the points, O, B, N, being in the same vertical plane; then, having set up a

staff, B S, whose length was equal to the height of the theodolite, we found the angles of elevation and depression to be as follows:—

At the station, N, $\begin{cases}\text{object, O, elev. } 3° \ 59' = \text{ang. O A H.} \\ \text{top of staff, S, depr. } 39' \text{ ang. H A S.}\end{cases}$

At the other station, B, the elev. of O $= 5° \ 52' =$ ang. PSO.

Hence the horizontal distance, B R, the height, R O, and also G N, the height of the station, N above B, are required.



Method of construction.—Draw R G indefinitely, to represent an horizontal line, and from any point, B, draw the slope, B C, making the angle, G B C, $= 39'$ (the angle, H A S); then, from a scale of equal parts, set off B N $=$ 642, and B S perpendicular to B G, and equal to the height of the theodolite, N A; let S A be parallel to B C, and equal to B N, and A G parallel to S B; also draw the horizontal lines, A H, S P; then if the angles, O S P, O A H, are made equal to 5° 52', and 3° 59' the angles of elevation respectively, and O R is perpendicular to G R, the figure will be constructed.

Calculation:—

Angle O A H $= 3° \ 59'$

H A S $=$ 39′ . . its supplement 179° 21′ ang. A S P

Subtract 5 52 ang. O S P

Angle O A S $=$ 4 38

173 23 ang. O S A

Therefore, the angles of the triangle, O A S, are

$$O S A = 173^{\circ} 29'$$
$$O A S = 4\ 38$$
$$A O S = 1\ 53$$

As *sine* of A O S, 1° 53′ . . .	log.	8.516726
		1·483274
Is to A S, 642	log.	2·807535
So is *sine* of O A S, 4° 38′ . . .	log.	8·907297
To S O	log.	3·198106

Then,

As *sine* S P O, 90°	log.	10·000000
Is to S O	log.	3·198106
So is *sine* O S P, 5° 52′	log.	9·009515
To the height O P, 161·3 . . .	log.	2·207621

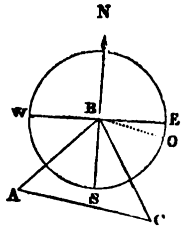
S O	log.	3·198106
5° 52′ *cosine*	log.	9·997719
Dist. S P = B R = 1569·7	log.	3·195825

As *sine* angle N G B, 90° . . .	log.	10·000000
Is to N B, 642	log.	2·807535
So is *sine* N B G. 39′	log.	8·054781
To N G, 7·3 yards, nearly . . .	log.	0·862316

And if S B (P R) the height of the theodolite, when standing on the ground, be added to O P, we shall have the height of O above the horizontal line, G R.

In surveying with a prismatic compass (numbered as described at page 5), *an object,* C, *bore* 146° 15′ E., *and when we had gone* 240 *yards in a direction bearing*

45° W., *the object bore* 101° 15′ E. *Required its distance from the stations* B *and* A.



Construction.—Let the circle, whose centre is B, represent the compass; N., E., W., S., the north, east, west, and south points: draw B O, making the angle N B O = 101° 15′; B C, to make the angle N B C = 146° 15′; B A, so as to make the angle S B A = 45°; also make B A = 240 from a scale of equal parts; then, if A C be drawn parallel to B O, C will be place of the object.

Method of *calculation:*—

$$\text{In the triangle A B C} \left\{ \begin{array}{r} \text{Angle A B C} = 78^\circ\ 45' \\ \text{A C B} = 45\ \ \ 0 \\ \text{B A C} = 56\ \ 15 \end{array} \right.$$

And the side B A = 240, whence A C = 332, and B C = 282 yards.

The method of finding your place on a map or plan by means of a compass, either when reconnoitring a country with the aid of the former, or when filling-in the latter, has been described in Section IV. But it may happen that you have no compass, or that the variation of the needle is not exactly known; perhaps, also, a true meridian line may not have been laid down. In any one of these cases your position may be fixed by taking two angles with a theodolite or pocket-sextant to three or more objects, whose distances apart are known. Several ingenious problems have been devised in illustration of the cases that may arise from exercising this mode of finding your place; a few of which I shall present to my readers. They all

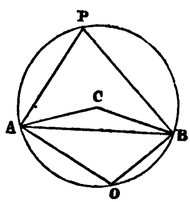
depend, however, upon a single geometrical problem, namely, that by which we are enabled upon a given line to describe a segment of a circle, which shall contain a given angle. That this is necessary the following observations will show :—

Two objects can *only* be seen under the *same* angle, from places situated in the circumference of an imaginary circle, passing through those objects and the place of observation.

If the angle under which those objects appear be less than 90°, the place of observation will be somewhere in the arc bounding the greater segment, and the objects will be seen under the same angle from every part of that arc.

If the angle under which the objects are seen be more than 90°, the place of observation will be somewhere in the arc of the lesser segment, and those objects will be seen under the same angle from every part of the arc bounding that segment. Hence, from the situation of three known objects, we are enabled to determine the station-point with accuracy.

On a given line, A B, *to describe a segment of a circle that shall contain a given angle.*

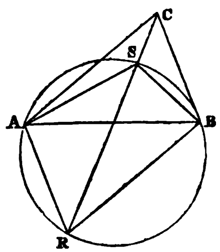


At the extremities, A B, of the given line, make each of the angles, C A B, C B A, equal to the difference of the proposed angle and a right one; and with C A or C B describe a circle: then the segment, A P B, on the same side of A B as the centre, C, will contain the given angle when it is *less* than a right one; and the opposite segment, A O B, will contain it when it is *greater*.

If A, B, C, *be three objects, whose distances from each other are* A B = 4516, A C = 4809, B C = 3018 *yards:*

and suppose at the station, S, *we observe the angles* C S B = 117° 56′, B S A = 110° 12′; *it is required to find the distances from the station to the three objects.*

By *construction.*—If the triangle, A B C, be laid down with the three given distances, and segments of circles described upon any two sides to contain the angles they subtend, the intersection of the arcs will evidently be the station, whether it falls within or without the triangle. But the following method is rather more simple:—About A B



describe a circle, so that the segment, A B S, shall contain the angle 110° 12′: make the angle B A R = 62° 4′ the supplement of 117° 56′ (C S B), join C R; and S, where it intersects the circle is the station. For if A S, S B, B R, are drawn, the angle A S B is = 110° 12′ by construction; and R S B being equal to R A B (standing on the same arc), or 62° 4′, the angle C S B, which is its supplement, will be 117° 56′, the other observed angle.

Calculation.—The three sides 4516, 4809, 3018 give the angle A B C = 76° 28′.

Angle A B R (=A S R, the supplement of A S C)	= 48° 8
B A R	= 62 4
A R B	= 69 48

These, with the side A B give B R = 4251·3.

The angle R B C = 48° 8′ + 76° 28′ = 124° 36′, which, with the two including sides, give R C B = 32° 47′, and C R B = 22° 37′.

Now, S A B = S R B = 22° 37′; therefore all the angles of the triangles A S B, B S C are given, namely:—

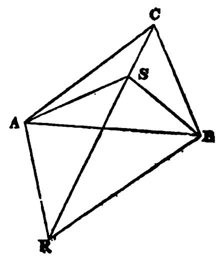
S A B = 22° 37′	S C B = 32° 47′
A S B = 110 12	C S B = 117 56
S B A = 47 11	S B C = 29 17

Whence the distances, S A, S B, S C, are found to be 3530, 1851, 1672 yards, respectively.

When the station is without the triangle (suppose at R), it is evident the circle must be described so that the outward segment, A R B, shall contain the whole observed angle, A R B; then, if the angles, A B S, B A S, be made respectively equal to the observed angles, A R C, B R C, and C R drawn through S, it will give the station, R.

If the whole observed angle, A R B, should be equal to the supplement of the angle, A C B, the circle will pass through the point, C, in which case the problem is indeterminate; for the angles standing on the chords, B C, A C, would be the same in all points of the arc, A R B.

It appears from the preceding construction that it is not necessary to describe a circle. For example, if the station be within the triangle, then the angles, B A R, A B R, being made equal to the supplements of the observed angles, B S C, A S C, the intersection of A R and B R gives the point, R; then, if the angle, A B S, be made equal to the angle, A R C, B S will meet R C in S, the station. On the contrary, when the place of observation is without the triangle,

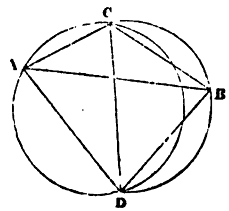


the angles, S B A, B A S, are made equal to the observed angles, A R C, B R C, respectively; then C R being drawn through S, and the angles, A B R, B A R, made equal to A S R, B S R, B R and A R will meet C R in R, the station.

In this latter case, however, when the point, S, falls near the object, C, the *construction* may give the point, R, considerably wide of the truth.

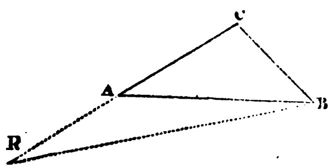
Or by another method.

Let A, C, B, be the three points forming a triangle, whose distances from each other are known, and that we want to determine the situation of a point, D. Observe the angle, A D C, C D B; and on A C describe the segment of a circle that will contain the angle, A D C; and on BC a segment to contain the angle, CDB; then will the point, D, where the two circles intersect, be the place of observation.



CASE 2. *When the given place or station,* R, *is without the triangle made by the three given objects,* A, B, C, *but in a line with one of the sides produced.*

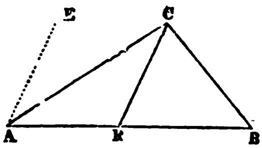
Measure the angle, A R B, then the problem may be easily solved, either by construction or calculation.



By construction.—Subtract the measured angle, A R B, from the angle, C A B, and you obtain the angle, A B R; then at B, on the side B A, make the angle, A B R, and produce C A to meet B R at R, the station.

By calculation.—In the triangle, A B R, the angle, R, is obtained by observation; the angle, B A R, is the supplement of the angle, C A B, to 180°; two angles of the triangle being thus known, the third is also known; we have, therefore, in the triangle, A R B, the side, A B, and all the angles, to find A R and R B.

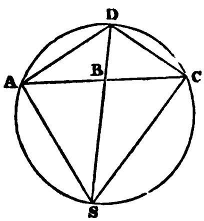
CASE 3. *When the station-point is in one of the sides of the given triangle.*



By construction.—Measure the angle, C R B, and make the angle, B A E, equal to the observed angle; then draw C R parallel to A E, and R is the station-point required.

By calculation.—Find the angle, B, in the triangle, A B C, then the angles, B and B R C, being known, we obtain R C B; and, consequently, as sine angle, B R C, is to B C, so is sin. angle, R C B, to B R.

CASE 4. *When the three given places are in a straight line.*



By construction.—A, B, C are three points in a straight line, whose distances from each other are known. Observe the angles, A S B, C S B; then on A C describe a circle, so that the segment, A S C, shall contain an angle equal to the whole angle, A S C, Make the angle, C A D = C S B, and A C D = B S A; and from the point of intersection, D, draw a line through B to meet the circle at S, which will fix S, the station.

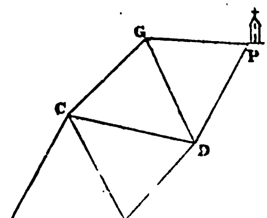
By *calculation.*—In the triangle, A D C, we have given the side, A C, and all the angles, to find D C. In the triangle, D B C, we have B C, D C, and the included angle, to find the angles, B D C and D B C. In the triangle, B C S, we have B C and the angles to find B S and C S.

The above instances are sufficient to illustrate this problem, which is extensively useful in maritime surveying to determine the positions of rocks, sands, &c., at a distance

from the coast; but the operation may be very much shortened by making use of an instrument called a *station-pointer*, which can be set to the observed angles and then applied to the map or plan, so as to fix the station at once; or the observed angles may be drawn on transparent tracing-paper, and then applied to the plan; which method will be found to answer the purpose.

The following trigonometrical problem will serve to illustrate the method of carrying on a triangulation for any survey, whether the object be to find the distance between two given points, or for any other purpose whatever.

Let A B *be a base of* 2 *miles, or* 3520 *yards; and suppose poles or flag-staves are set up at the stations,* A, B, C, D, G*; and that the angles at those stations, taken with a theodolite, are the following:—*



Namely,	C A B = 64° 29′	D C G = 73° 58′
	C B A = 75 15	C D G = 51 27
	A C B = 40 18	C G D = 54 33
	Sum . 180 2	*Sum* . 179 58
	B C D = 53° 41′	D G P = 71° 7′
	C B D = 64 8	G D P = 46 51
	B D C = 62 14	
	Sum . 180 3	

It is required to find the distance of the spire, P, *from the station,* A.

The error in the sum of the three observed angles of the first triangle is 2′; in the second, 3′; and in the third, 2′. The angle at P, in the fourth triangle, is supplemental.

But no certain rule can be given for correcting the observed angles; this must be left to the judgment of the observer, who, from circumstances, will seldom be at a loss to point out where the greatest uncertainty lies. To make the calculation, however, we will suppose the corrected angles are:—

C A B =	64° 28′	D C G =	73° 58′
C B A =	75 14	C D G =	51 28
A C B =	40 18	C G D =	54 34
	180 0		180 0
B C D =	53° 40′	D G P =	71° 7′
C B D =	64 7	G D P =	46 51
B D C =	62 13	G P D =	62 2
	180 0		180 0

Then,

A C B = 40° 18′ . .	*sin.*	9·810763	
		0·189237	
A B = 3520 . .	log.	3·546543	
C A B = 64° 28′ .	*sin.*	9·955368	
		3·691148	log. C B.
B D C = 62° 13′	*ar. co. sin.*	0·053196	
B C D = 53 40 . .	*sin.*	9·906111	
		3·650455	log. B D = 4471·5
		3·744344*	

* When the two first terms of the proportion are repeated, the operation may be somewhat abridged by taking the sum of the arithmetical complement and the log. of the second term, instead of setting them down separately a second time.

Thus, 3·744344 is the sum of $\begin{cases} 3·691148 \\ 0·053196 \end{cases}$

		3·744344
C B D = 64° 7′ . .	*sin.*	9·954090
		3·698434 log. C D.
C G D = 54° 34′	*ar. co. sin.*	0·088954
D C G = 73 58 . .	*sin.*	9·982769
		3·770157 log. G D.
G P D = 62° 2′	*ar. co. sin.*	0·053931
D G P = 71 7 . .	*sin.*	9·975974
		3·800062 log. D P = 6310·5

Now, from the sides, B A, B D, and the included angle, 139° 21′, we get the angle, B D A = 17° 48′, and A D = 7501·1 yards.

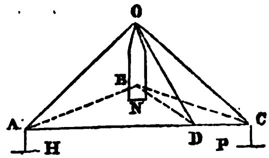
And if B D A be taken from 160° 32′, the angle, B D P, there remains 142° 44′, the angle, A D P, which, with the including sides A D = 7504·1, and D P = 6310·5, will give the distance from P to A = 13093 yards.

When triangles are carried on from the original base in all directions, the distances towards the extremities may, in some respect, be verified by independent calculation.

REDUCTION OF OBLIQUE ANGLES TAKEN WITH A SEXTANT, TO THE CORRESPONDING HORIZONTAL ANGLES.

When describing the uses of the pocket-sextant, mention is made (page 89) of angles taken with that instrument not being always, like those observed with a theodolite, *horizontal ones;* but frequently in planes oblique to the horizon. Thus:—

Suppose O N *is an object standing on the horizontal plane,* H N P: H A *and* C P *two staves or rods, equal in*



height to that of the eye; and let the plane, A B C, *be parallel to the horizontal plane,* H N P; *also suppose* H P *or* A C *is a base of 250 yards; and that the angles taken in the plane,* O C A, *are* O A C = 56° 46′, *and* O C A = 62° 54′; *the angles of elevation* O A B, O C B, *being* 6° 40′ *and* 7° 6′ *respectively. Hence the height, and horizontal distances,* A B, C B, *are required.*

When one of the sides (A C) including an angle (O A C) oblique to the plane of the horizon, is horizontal, the angle is reduced to the corresponding horizontal angle, by the following proportion:—

As the *cosine* of the angle of elevation (O A B)
Is to the *cosine* of the given angle (O A C),
So is the *radius* or *sine* of 90°
To the *cosine* of the reduced angle (B A C).

For let D B O be a vertical plane, and the angle, A D O, a right one: then the triangles, A B O, D B O, being also right-angled at B, we have,

Sine A B O, 90° : A O :: *sine* A O B : A B.
Sine A D O, 90° : A O :: *sine* A O D : A D.

Therefore, by equality—

Sine AOB : *sine* AOD :: A B : AD :: *sine* ADB, 90° : to *sine* A B D; or, *sine* A O B : *sine* A O D :: *sine* 90° : *sine* A B D.

But A O B is the complement of the elevation; A O D the complement of the observed angle, O A C; and A B D that of the reduced angle, B A C; therefore,

As *cosine* 6° 40′	log.	9·997053
		0·002947
Is to *cosine* 56° 46′	log.	9·733820
So is *sine* 90°	log.	10·000000
To *cosine* 56° 31′, the reduced angle B A C.	log.	9·741767

As *cosine* 7° 6′	log.	9·96657
		0·003343
Is to *cosine* 62° 54′	log.	9·658531
So is *sine* 90°	log.	10·000000
To *cosine* 62° 40′, the reduced angle A C B.	log.	9·661874

Therefore, the angles of the triangle AOC, reduced to the horizontal plane, are

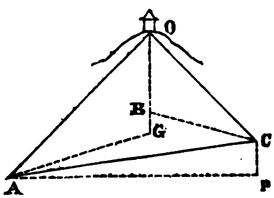
$$\begin{aligned} BAC &= 56°\ 31' \\ ACB &= 62\ \ 40 \\ ABC &= 60\ \ 49 \end{aligned}$$

And the side, A C, being 250 yards, we shall have A B = 254·4, and C B = 238·8 yards; whence B O = 29·7 yards: to this add N B, the height of the observer's eye above the horizontal plane, H N P, and the sum will be the whole height, N O.

But the distances, A B, C B, and height, B O, may be calculated without any reduction of angles; for A C, and all the angles of the triangle, AO C, being given, the sides, A O, C O, are found, and then the right-angled triangles, A B O, C B O, will give A B, C B, and B O, at three porportions.

And, should it be necessary, the reduced angles may be found from the sides of the triangle, A B C.

If A *and* C *are two stations on sloping ground;* O *an object on the top of a hill; and the angles,* O C A, O A C *(measured with a sextant), equal* 79° 29′, *and* 63° 11′, *respectively: also suppose the angle of elevation at* A *is* 6° 36′, *at* C = 5° 22′ : *what are the horizontal distances and height of the object;* A C *being* = 410 *yards?*



Let O G be perpendicular, and A G, C B, parallel to the horizon: then A G, C B, are the horizontal distances.

In the triangle, A O C, the angles are,

$$\begin{aligned} OCA &= 79^\circ\ 29' \\ OAC &= 63\ \ 11 \\ AOC &= 37\ \ 20 \\ \text{And } AC &= 410 \text{ yards.} \end{aligned}$$

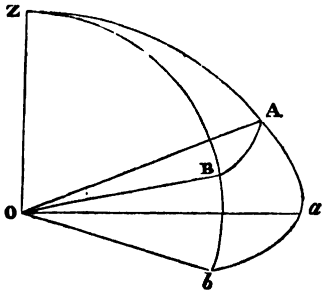
Whence A O = 664·7, C O = 603·4, these hypothenuses, with the angles of elevation, O A G, O C B, in the right-angled triangles, A G O, C B O, give

A G = 660·3, O G = 76·4, C B = 600·7, O B = 56·4 yards.

And the difference of O G and O B is 20 yards = B G = C P, the difference in the heights of the stations, A P, being supposed horizontal.

The sides, A C, C P, will give A P. And the angles of the triangle, A O C, when reduced to the horizon, may be found from the horizontal distances, A P, A G, C B, taken as the sides of a triangle.

We will add another instance:



Let O *be the station of the observer;* A B *the two objects between which an angle is measured; then the angle subtended by them at* O, *is* A O B, *which* A B *measures: but if* Z *a*, Z *b*, *are each* = 90°, *a b*, *and not* A B, *measures the angle*, *a* Z *b*, *which is the angle required. We have, then, from the abserved angle*, A O B, *and the observed zenith distances*, Z A, Z B, *to find the angle*, *a* Z *b*, *or, which is the same thing, to find the difference of the angles*, A O B, *a* Z *b*.

The last figure will be found useful, as showing the principle upon which the reductions are made; but I shall not give the calculation: niceties of this kind being unnecessary in ordinary military surveying.

PORTABLE TRIGONOMETRY, WITHOUT LOGARITHMS.

[The following useful application of Trigonometry, by means of the natural sines, tangents, &c., is taken from an early number of that valuable periodical, the "Mechanics' Magazine;" and will be found particularly suited to the purposes of the Military Surveyor.]

"IN all the more elaborate and refined operations of trigonometry, as well as their applications to navigation, astronomy, and geodesic surveying, it is not only desirable, but necessary to employ some of the larger logarithmic tables, as those of Hutton, Babbage, Callet, Taylor, &c., both to save time and to ensure the requisite accuracy in the results. But, in the more ordinary operations, as in those of common surveying, ascertaining inaccessible heights and distances, reconnoitring, &c., where it is not very

usual to measure a distance nearer than within about its thousandth part, or to ascertain an angle nearer than within two or three, or in very rare cases within one minute, it is quite a useless labour to aim at greater accuracy in a numerical result. Why, for example, should I compute the length of a line to the fourth or fifth place of decimals, when it must depend upon another line, whose accuracy I cannot ensure beyond the unit's place? Or, why compute an angle to seconds, when the instrument employed does not ensure the angles in the data beyond the nearest minute?

Hence several mathematicians, as Euler, Legendre, Hutton, Bonnycastle, &c., have investigated approximating series, and other rules, for solving the cases of trigonometry without tables; yet, however ingenious their researches may have been, they have not led to any results of practical value, but simply furnish so many proofs how easy it is for scientific men, in their investigations, to miss the point of real utility.

It is truly extraordinary that, amid all this search for expedients, the obvious method, which I now beg to recommend and exemplify, has never been thought of. In the table herewith given, and which, set up in a bold, clear type, occupies only an octavo page, I have brought together the *natural* sines, tangents, and secants, to every degree in the quadrant; and have no doubt that this table, though only carried to five places of decimals, will be found sufficiently extensive and sufficiently correct for the various practical purposes to which I have adverted. And thus the surveyor, the architect, the civil or military engineer, furnished with this table, in one page, a 100-feet tape, a pocket sextant, or a portable theodolite, may take every angle and perform every computation that can occur in the most useful cases.

The requisite proportions must, it is true, be worked by multiplication and division, instead of by logarithms. Yet this by no means involves such a disadvantage as might seem at first sight. For when the measured lines are expressed by three, or at most by four, figures (and to give more only presents an appearance of accuracy which does not exist), the multiplications and divisions are performed nearly as quick, and in some cases quicker (as will be seen) than by logarithms. Besides which, the operations may often be shortened, by resolving numbers into their component factors, and by other contractions well known to practical men. Nay, if this were not the case, the circumstance would not present any serious objection: for, when a computation is not to be performed once in a month, it does not greatly signify whether you complete it in ten minutes or in twenty.

Then, as to accuracy: even in cases where the computer will have to take proportional parts for the minutes of a degree, the result may usually, if not always, be relied upon to within about a minute: and, recollecting that in the out-of-door operations he has it commonly at his option to fix his instrument at angles measured by *degrees* precisely, by simply advancing or receding for vertical angles, or moving to the right or left for horizontal ones, or a little varying the position of a station-staff; thus at once ensuring a simplified calculation and a more accurate result. The accuracy will also be augmented by some of the expedients which I shall explain as I go along.

A TABLE OF NATURAL SINES, COSINES, TANGENTS, COTANGENTS, SECANTS, AND COSECANTS,

TO EVERY DEGREE OF THE QUADRANT.

Deg.	Sines.	Cosines.	Tangents.	Cotangents.	Secants.	Cosecants.	
0	00000	1·00000	00000	Infinite.	1·00000	Infinite.	90
1	01745	99985	01745	57·2900	1·00015	57·2987	89
2	03490	99939	03492	28·6363	1·00061	28·6537	88
3	05234	99863	05241	19·0811	1·00137	19·1073	87
4	06976	99756	06993	14·3007	1·00244	14·3356	86
5	08716	99619	08749	11·4301	1·00382	11·4737	85
6	10453	99452	10510	9·51236	1·00551	9·56677	84
7	12187	99255	12278	8·14435	1·00751	8·20551	83
8	13917	99027	14054	7·11537	1·00983	7·18530	82
9	15643	98769	15838	6·31375	1·01246	6·39245	81
10	17365	98481	17633	5·67128	1·01543	5·75877	80
11	19081	98163	19438	5·14455	1·01872	5·24084	79
12	20791	97815	21256	4·70463	1·02234	4·80973	78
13	22495	97437	23087	4·33148	1·02630	4·44541	77
14	24192	97030	24933	4·01078	1·03061	4·13356	76
15	25882	96593	26795	3·73205	1·03528	3·86370	75
16	27564	96126	28675	3·48741	1·04030	3·62796	74
17	29237	95630	30573	3·27085	1·04569	3·42030	73
18	30902	95106	32492	3·07768	1·05146	3·23607	72
19	32557	94552	34433	2·90421	1·05762	3·07155	71
20	34202	93969	36397	2·74748	1·06418	2·92380	70
21	35837	93358	38386	2·60509	1·07114	2·79043	69
22	37461	92718	40403	2·47509	1·07853	2·66947	68
23	39073	92050	42447	2·35585	1·08636	2·55930	67
24	40674	91355	44523	2·24604	1·09464	2·45859	66
25	42262	90631	46631	2·14451	1·10338	2·36620	65
26	43837	89879	48773	2·05030	1·11260	2·28117	64
27	45399	89101	50952	1·96261	1·12233	2·20269	63
28	46947	88295	53171	1·88073	1·13257	2·13005	62
29	48481	87462	55431	1·80405	1·14335	2·06266	61
30	50000	86603	57735	1·73205	1·15470	2·00000	60
31	51504	85717	60086	1·66428	1·16663	1·94160	59
32	52992	84805	62487	1·60033	1·17918	1·88708	58
33	54464	83867	64941	1·53986	1·19236	1·83608	57
34	55919	82904	67451	1·48256	1·20622	1·78829	56
35	57358	81915	70021	1·42815	1·22077	1·74345	55
36	58778	80902	72654	1·37638	1·23607	1·70130	54
37	60181	79863	75355	1·32704	1·25214	1·66164	53
38	61566	78801	78129	1·27994	1·26902	1·62427	52
39	62932	77715	80978	1.23490	1·28676	1·58902	51
40	64279	76604	83910	1·19175	1·30541	1·55572	50
41	65606	75471	86929	1·15037	1·32501	1·52425	49
42	66913	74314	90040	1·11061	1·34563	1·49448	48
43	68200	73135	93251	1·07237	1·36733	1·46628	47
44	69466	71934	96569	1·03553	1·39016	1·43956	46
45	70711	70711	1·00000	1·00000	1·41421	1·41421	45
	Cosines.	Sines.	Cotangents.	Tangents.	Cosecants.	Secants.	Deg.

THE TABLE.

The preceding Table is so arranged that, for angles not exceeding 45 degrees, the sine, cosine, tangent, cotangent, &c., for any number of degrees, will be found *opposite* the proposed number in the *left-hand* column, and in the column under the appropriate word. When the number of degrees in the arc or angle exceeds 45 degrees, that number must be found in the *right-hand* column, and *opposite* to it in the column indicated by the appropriate word at the *bottom* of the table. Thus, the sine and cosine of 36 degrees are ·58778 and ·80902 respectively, the tangent and cotangent of 62 degrees are 1·88073 and ·53171 respectively; the radius of the table being unity, or 1.

The taking of proportional parts for minutes can only be done correctly (that is, independently of the rules of interpolation) in those parts of the table where the differences between the successive sines, tangents, &c., run pretty uniformly. In that case, the mode to be employed will be evident from a single example. Suppose we want the natural sine of 20° 16′. The sine of 21 degrees is 35837, that of 20 degrees is 34202; their difference is 1635. This divided by 60 gives 27·25, for the proportional part due to 1 minute, and that again multiplied by 16, gives 436, for the proportional part for 16 minutes. Hence, the sum of 34202 and 436, or 34638, is very nearly the sine of 20° 16′. And so of others. But observe that the operation may often be contracted, by recollecting that 10 minutes are 1-6th, 15 minutes are 1-4th, 40 minutes are 2-3rds of a degree, and so on. Observe, also, that for cosines, cotangents, and cosecants, the results of the operations for proportional parts are to be *deducted* from the value of the required trigonometrical quantity in the preceding degree.

USEFUL THEOREMS.

1. cosine $= \sqrt{(1 - \text{sin.}^2)}$
2. sine $\div$ cosine $=$ tangent.
3. cosine $\div$ sine $=$ cotangent.
4. $\text{sin.}^2 + \text{cos.}^2 = \text{rad.}^2$
5. $\text{rad.}^2 + \text{tan.}^2 = \text{secant.}^2$
6. $1 \div$ tan. $=$ cotangent.
7. $1 \div$ cotan. $=$ tangent.
8. $1 \div$ sine $=$ cosecant.
9. $1 \div$ cosine $=$ secant.
10. $1 \div$ cosecant $=$ sine
11. $1 \div$ secant $=$ cosine.
12. rad. $-$ cosine $=$ versin.

Thus, we may often, instead of dividing by a sine, multiply by the cosecant; instead of dividing by a tangent, multiply by the cotangent of the same arc; and so of others.

RIGHT-ANGLED TRIANGLES.

1. $(\text{hypoth.})^2 = \text{base}^2 + \text{perp.}^2$
2. $\text{base}^2 = (\text{hypoth.} + \text{perp.}) \times (\text{hypoth.} - \text{perp.})$
3. $\text{perp.}^2 = (\text{hypoth.} + \text{base}) \times (\text{hypoth.} - \text{base.})$
4. perp. $=$ base $\times$ tan. angle at base.
5. hyp. $=$ base $\times$ sec. angle at base.
6. perp. $\div$ base $=$ tan. angle at base.
7. base $\div$ perp. $=$ tan. angle at vertex.
8. hypoth. $\div$ base $=$ sec. angle at base.
9. hypoth. $\div$ perp. $=$ sec. angle at vertex.
10. base $\div$ hypoth. $=$ cosine angle at base.
11. perp. $\div$ hypoth. $=$ sine angle at base.

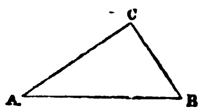
PLANE TRIANGLES, GENERALLY.

Case 1.—When a side and its opposite angle are two of the given parts.

Then, as any one side is to the sine of its opposite angle, so is any other side to the sine of its opposite angle.

The first term of the proportion must be the sine of a given angle, whose opposite side is also given, when a side is required. If an angle is required, begin the proportion with a given side opposite a given angle.

Remember that the three angles of every plane triangle, when added together, make precisely 180 degrees.



Case 2.—When two sides, and the angle included between them, are given, to find the third side: as suppose A C, A B, and the angle A are given. Then $CB = \sqrt{(AC^2 + AB^2 - 2\,AC \cdot AB \cdot \cos. A)}$. After C B is thus found, the angles C and B, if required, may be found by the rule in the 1st Case.

Case 3.—When the three sides are given, to find the angles. Find one angle, as suppose A, by the theorem,

$$\cos. A = (AC^2 + AB^2 - BC^2) \div 2\,AC \cdot AB;$$

then another angle by the rule to the 1st Case, and the third angle by taking the sum of the other two from 180 degrees.

Sometimes it will be better to determine one of the unknown angles, by means of a theorem for its *half*.

Thus, if half the sum of the three sides be denoted by S, we shall have

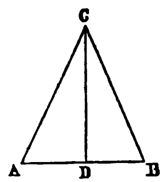
$$\sin. \tfrac{1}{2} A = \sqrt{\frac{(S - AB) \cdot (S - C)}{AB \cdot AC}}$$

I have thus brought together the most useful rules in plane trigonometry, that your practical readers may have all the requisite information before them in one place; and shall now conclude with a few examples in

HEIGHTS AND DISTANCES.

And here, for the sake of facilitating the comparison with a well-known book, I shall select from the second volumn of "Hutton's Course of Mathematics."

Example 1.—Two stations, A and B, are assumed in a horizontal plane, and it is required to find their distance from an inaccessible object, C, in the same horizontal plane.



A B is measured = 200, the angle A is found to be 68° 2′, and B = 73° 15′. Required A C and B C. (Hutton, p. 24.)

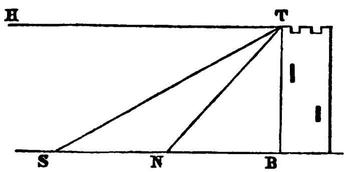
Here $180° - (A + B) = 38° \ 43' = C$. Then proportioning as before explained for the minutes, we have sine C = sin. 38° 43′ = ·62545; sin. A = sin. 68° 2′ = ·92739; sin. B = sin. 73° 15′ = ·95755. Then, working with these numbers and A B = 200, we have, from Case 1,

sin. C: AB :: sin. B: AC=306·19; Dr. H.'s answer is 306·19
sin. C: AB :: sin. A: BC=296·55; Do. 296·54

I omit the work at large to save room.

Note.—In a great majority of cases, an inacessible distance may be obtained by a still simpler process. Thus, choose the first station at D, so as to make a right angle, C D A, with the line A B; then set the sextant, or other instrument for measuring angles, to any suitable angle expressed in degrees, 70°, 60°, 54°, 52°, 45°. &c., and retire from D along D A, until the angle, C A D, accords with that to which you have set the instrument. Then, D C = D A × tan. A, and A C = D A × sec. A.

Example 2. —From the top of a tower, by the sea-side, of 143 feet high, the angle of depression of a ship's bottom was observed to be 35°: what was the ship's distance from the bottom of the wall? (Hutton, b. 25.)



In the annexed figure, where T H, B S, are horizontal, T B vertical, the latter is given = 143; also angle H T S = 35°, whence S T B = 90° − 35° = 55°. But B S is evidently the tangent of the angle S T B to the radius T B. Hence, B S = T B × tan. S T B = 143 × 1·42815 = 204·22, agreeing with Dr. H.'s answer.

Example 3.—Wanting to know the distance between two inaccessible objects, N S (preceding figure), on a horizontal plane, the angles S T B = 64½°, N T B = 33°,

were taken from the top of a tower whose height, B T, was known to be 120 feet. Required N S. (Hutton, p. 24.)

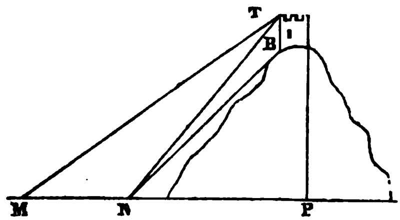
Here S N is evidently equal to the difference of the tangents of S T B and N T B, to the radius T B.

Now, the differences of the tangents above 60° increasing rapidly, the common use of the proportional parts would give the tangent of 64° 30′ too great. I therefore, find the cotangent of 64° 30′=·477 nearly, and from the principle of theor. 7, find 1÷·477=2·0964=tan. 64½°. The tan. of 33° = ·64941. Therefore, (·20964 – ·64941) 120= 1·44699 × 120 = 173·6388 = S N. Dr. H.'s answer is 173·657, differing by about the 10,000th part.

Example 4.—Wanting to know the height of an inaccessible tower, I took two angles in the same vertical plane, viz., N=58°, S=32° (preceding figure), and measured the horizontal distance, N S, between the stations = 300. Required the height, B T, of the tower, and my distance N B, from it at the nearest station. (Hutton, p. 25.)

In this case, by simply reversing the process in the last example, N S, divided by the difference of the tangents of S T B and N T B, or the difference of the cotangent of S and N, will give B T; and B T × cot. N = B N. But cot. 32°=1·60033, and cot. 58°=·62487, their diff.= ·97546. Hence, 300÷·97546=307·55=B T; and 307·55 ×·62487=192·17=B N. Dr. H.'s answers are 307·53 and 192·15; and the logarithmic method requires 12 lines, oesides turning to several different pages of the tables.

Example 5.—In order to find the height of a tower, T B, that stood on the top of a hill, at two stations, N, M, whose horizontal distance measured 200 feet, I took the vertical angles, P N B=40°, P N T=51°, and P M T=33° 4′,



all in the same vertical plane. Required T B. (Hutton, p. 26.)

This example may be worked either by means of the tangents and cotangents, or by the sines; let us here employ the latter. Sin. M T N = sin. (T N P − T M P) =sin. 17° 15′=·29654; sin. T M N=sin. 33° 45′=·55556, found by the proportional parts, as before described; sin. B= sin. 50°= sin. 130°=·76604; sin. B N T = sin.(51° − 40°) = sin. 11° = ·19081. With these numbers and M N = 200, work the following proportions:—

sin. T M N : M N :: sin. T M N : T N=374·695

and sin. B : T N :: sin. B N T : B T=93·3313. Dr. H.'s answer is 93·33148.

Example 6.—Wanting to know the distance between two headlands, I measured from each of them to a certain point inland, and found the two distances to be 735 and 840 yards, and the horizontal angle between those two lines 55° 40′. Required the distance. (Hutton, p. 27.)

Here, referring to the figure in Case 2, Plane Triangles, there are given A C = 735, A B = 840, and angle A = 55° 40′. Observe, also, that 735 = 105 × 7, and 840 = 105 × 8; and that, therefore, we may proceed as though A C were 7 and A B 8; multiplying the final result by 105.

The cosine of 55° 40′ = cos. 55° − $\frac{2}{3}$ diff. cosines of 55°

and $56° = \cdot564$ very nearly. Hence, taking the expression in Case 2, we have—

$$\begin{aligned} C\,B &= 105\,\sqrt{(7^2+8^2-2\cdot7\cdot8\times\cdot564)} \\ &= 105\,\sqrt{(49+64-63\cdot168)} \\ &= 105\,\sqrt{49\cdot832} \\ &= 105\times7\cdot05917 \\ &= 741\cdot21 \text{ yards.} \quad \text{Dr. H.'s answer is } 741\cdot2. \end{aligned}$$

The above will suffice to exemplify the manner of operation, as well as to prove the accuracy of the method; which, as will thus appear, is greater than I have hypothetically assigned it.

In what is here done, I shall not, I trust, be supposed attempting to supersede the use of the excellent tables referred to at the commencement of this paper, or the correct theoretical processes which they so greatly facilitate. I am solely anxious to explode all the crude and usually erroneous tentative methods adopted by those who are not conversant with the nature and use of logarithms, by showing that, without the aid of those artificial numbers, a table of natural sines, tangents, &c., comprehended in a single page, will enable a computer, by simple operations in decimal arithmetic, to solve problems in trigonometry, and inaccessible heights and distances, with all the accuracy that can be desired by practical men.

The same table will be found of equal utility in the mechanical inquiries which relate to the parallelogram of forces, oblique pressures, motions on inclined planes, the usual practice of gunnery, &c. But, fearing that I shall have already greatly encroached upon your pages, I cannot hint at these applications now.

I am not, however, without hopes that what is here done will stimulate some individual of more leisure than myself

to turn his attention to the abbreviation of a table of logarithms. I have seen such a table in a single sheet; and M. Wronski proposed to reduce it to a single page. If, however, a correct table to five places of decimals could be presented in about four pages, then two more pages might contain such a table as the preceding, and an analogous table of logarithmic sines, tangents, &c. A single sheet might thus be made to exhibit all the tables, precepts, and rules, necessary in the common practice of trigonometry, and in the computation of annuities and reversions. Much shall I rejoice if some of your correspondents enable you to present to the public so valuable a gift."

P. M. W.

ON LEVELLING.

SECTION XVIII.

OBSERVATIONS — LEVELLING WITH A MASON'S LEVEL — WITH BONING-STAVES — DESCRIPTION OF A SPIRIT-LEVEL — LEVELLING STAVES — METHOD OF LEVELLING WITH A SPIRIT-LEVEL — DRAWING SECTIONS — LEVELLING WITH A THEODOLITE — TRACING CONTOUR LINES.

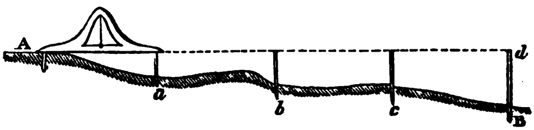
LEVELLING may be considered as a branch of surveying; a knowledge of it, therefore, is necessary for the military surveyor. He may have to use a sloping base for a survey, which must be reduced to the true horizontal distance by levelling. Or he may have to drain a marsh; to form a road, either level, or with a certain degree of inclination; to take sections of ground for various purposes; to take profiles of fortifications and field works, &c. All such operations are performed by some kind of levelling process, as will be shown in the course of the following pages.

Writers on levelling generally commence the subject with the theoretical, and then proceed to the practical part; but I venture to think it better to set the pupil at once to work with his instruments, show him how to take levels, and thence lead him on to investigate the theoretical part, rather than perplex him at first with the spheroidal form of the globe, and its influence on levelling operations, as occasioning calculations on account of curvature. Surely this,

and the theory of refraction, had better be reserved until the student shall have obtained sufficient knowledge of levelling to take an interest in the art; particularly as, in practice, corrections for curvature and refraction are very rarely applied, common levelling operations being usually so managed as to render such corrections unnecessary.

There are three kinds of levelling instruments in use, namely, the *ordinary Mason's level, Boning-staves,* and the *Spirit-level.* The two first are often employed by military men when a spirit-level cannot be obtained; or for setting off slopes, and other minor purposes.

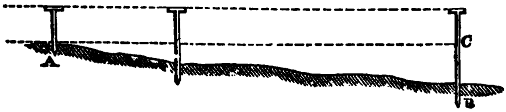
The method of using a mason's level is thus:—Suppose we want to know the difference of level between a point, A, and another at B. Drive a picket at A down to the



surface of the ground, and another, distant a few inches less than the length of the *level,* at *a,* until the eye perceives that the head of the latter is nearly on a level with A; then set the *level* to rest on the two pickets, and the *plumb-line* will show when their heads are truly level. A third picket is then driven in at *b,* a fourth at *c,* &c., to the heads of which the level is successively applied; and the length of the picket, B *d,* is the difference of level required: the heads of all the pickets will then be on the same level, represented by the dotted line, A *d.*

The same operation is more quickly performed by means of *boning-staves,* which are simply staves of equal length (usually three feet), having a T head. To level with their assistance, a mason's level is used for the first two pickets, as before; then a third picket being driven at any conve-

nient distance, a boning-staff is held upon each, and the third picket is driven down until the observer a A can see



that the upper surfaces of the T heads are all in an exact horizontal line: the operation may then be continued by driving in a picket beyond B, to which the boning-staff at A must be removed. Instead of driving a picket at B, a measuring-rod is often used, which being held perfectly upright, a boning-staff is pressed against it, and caused to slide up or down, until its head agrees with those of the other two; when the difference of level is of course the distance between the foot, C, of the boning-staff, and B that of the measuring rod. Observe that the boning-staves are to be held transversely, or at right angles to the position in which they are shown in the diagram.*

It is evident that levelling by means of a mason's level or boning-staves is only suited to very short distances; and they are but rough methods when compared to that by the spirit-level; for such is the accuracy of the process of levelling with a spirit-level, that an operation carried along a distance of several miles will not produce an amount of error equal to what will generally arise in the course of a few hundred yards, when using the former instruments.

* Engineers regulate slopes, such as those required in fortification, making roads, &c., by means of what is termed *Boning*. The operation is performed by driving a picket at the top, and another at the bottom of a given descent for the distance; upon these two boning-staves are held, while intermediate pickets are driven down until boning-staves, held on the heads of the latter, are seen to be in the same inclined plane with those placed at the top and bottom of the slope.

Of spirit-levels there are now three in use—namely, the Y level, Troughton's improved level; and Gravatt's level. these are all carefully described, and their several adjustments given, in Mr. Simms' work on instruments. I shall confine myself to the account of the Y level, as represented in plate XVII.*

This instrument has an achromatic telescope mounted in Ys, like those of the theodolite; and is furnished with a similar system of cross-wires, for determining the axis of the tube, or line of collimation. By turning the milled-headed screw, A, on the side of the telescope, the internal tube, *a*, will be thrust outwards, which carrying the object-glass, it is by this means adjusted to its focal distance, so as to show a distant object distinctly.

The tube, *c c*, carrying the spirit-bubble, is fixed to the under part of the telescope, by a joint at one end, and a capstan-headed screw at the other, which sets it parallel to the optical axis of the telescope. One of the Ys is supported in a socket, and can be raised or lowered by a screw, B, to make the telescope perpendicular to the vertical axis. Between the two supports is a compass-box, C (having a

* I find the following remarks on spirit-levels in Mr. Henry J. Castle's work on Surveying, &c.:—

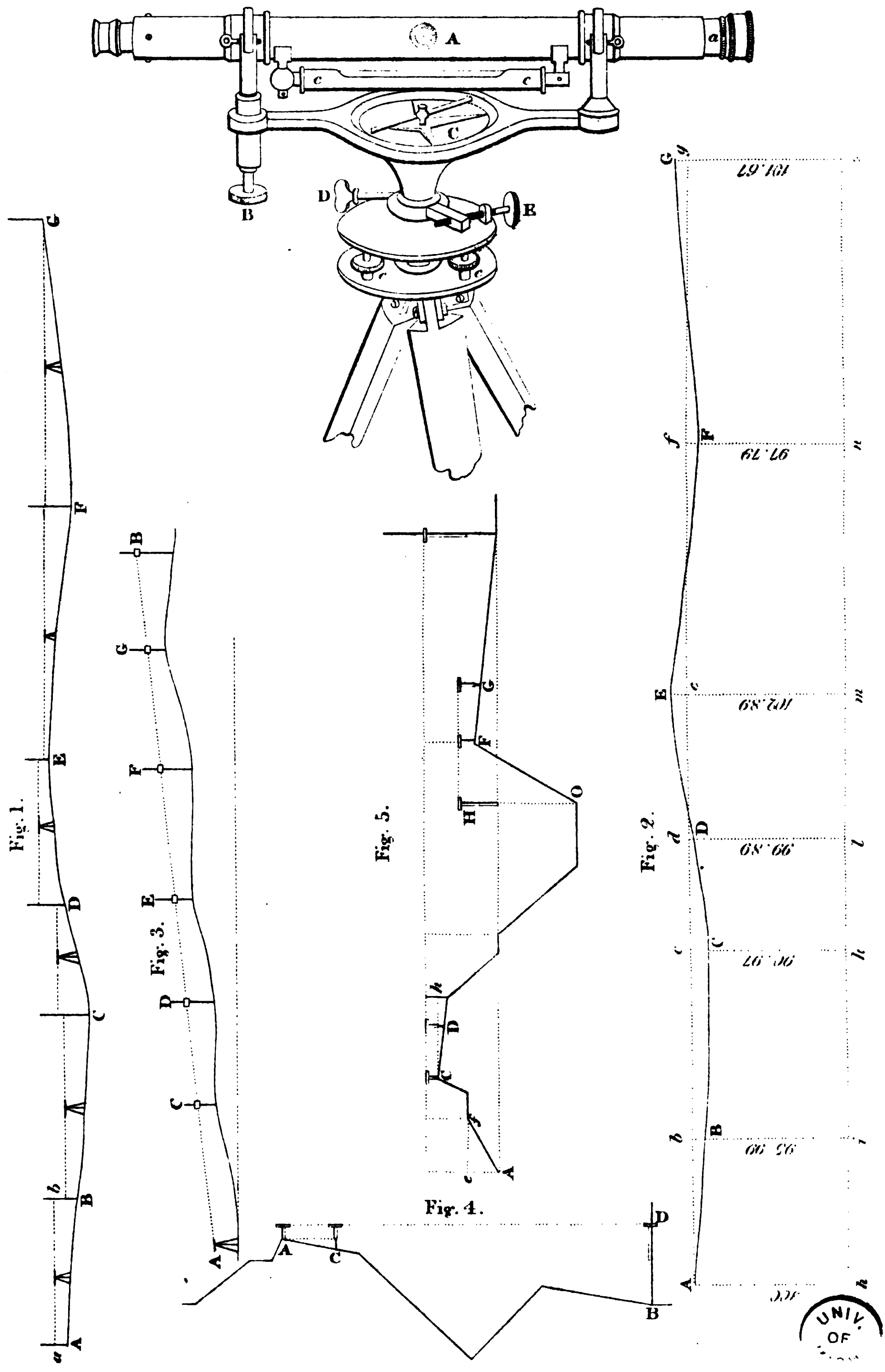
"In trial and check levels I would recommend Gravatt's or Troughton's, being calculated by their lightness, and non-tendency of disarrangement, to get rapidly over the ground.

"For the main sections, at every two chains, I should prefer the Y level; and for putting down the rails, the formation of roads, and all work where accuracy, and not expedition, is required, I should decidedly give it the preference.

"There is one fault I have found with most levels, that the tube of the telescope is not long enough to admit of reading off the staff within short distances, few reading within half a chain. Having had placed for myself, in addition to the extending tube at the object-end, another at the eye-glass to remedy this defect, I have been enabled to read within three yards; to this inner tube, of course, was attached the diaphragm of the cross wires and the lengthening eye-piece."

PLATE XVII.

THE Y SPIRIT LEVEL.



contrivance to throw the magnetic needle off its centre when not in use) : it is convenient to take bearings, and is not necessarily connected with the operations of levelling, but extends the use of the instrument, making it a rough circumferentor. The whole is mounted on parallel plates, and three legs, the same as a theodolite.

It is evident, from the nature of this instrument, that three adjustments are necessary. First, to place the intersection of the wires in the telescope, so that it shall coincide with the axis of the cylindrical rings on which the telescope turns; secondly, to render the level parallel to this axis; and lastly, to set the telescope perpendicular to the vertical axis, that the level may preserve its position while the instrument is turned quite round upon the staves.

TO ADJUST THE LINE OF COLLIMATION.

The eye-piece being drawn out to see the wires distinctly, direct the telescope to any distant object, and by the screw, A, adjust to distinct vision;* bring the intersection of the cross wires to coincide with some well-defined part of the object, then turn the telescope round on its axis, as it lies in the Ys, and observe whether the coincidence remains perfect during its revolution; if it does, the adjustment is correct; if not, the wires must be moved one-half the quantity of error, by turning the little

* This eye-piece must be first drawn out until the cross wires are perfectly well defined; then the object-glass moved till distinct vision is obtained without parallax, which will be the case, if on looking through the telescope at some distant object, and moving the eye sideways before the eye-glass, the object and the wires remain steadily in contact; but if the wires have any parallax the object will appear flitting to and from them.

screws near the eye-end of the telescope, one of which must be loosened before the opposite one is tightened, which, if correctly done, will perfect this adjustment.

TO SET THE LEVEL PARALLEL TO THE LINE OF COLLIMATION.

Move the telescope till it lies in the direction of two of the parallel plate screws, *e e*, (the clips which confine the telescope in the Ys being laid open), and by giving motion to the screws, bring the air-bubble to the middle of the tube, shown by the two scratches on the glass. Now reverse the telescope carefully in its Ys, that is, turn it end for end; and should the bubble not return to the centre of the level as before, it shows that it is not parallel to the optical axis, and requires correcting. The end to which the bubble retires must be noticed, and the bubble made to return one half the distance by the parallel plate-screws, and the other half by the capstan-headed screw at the end of the level; when, if the halves have been correctly estimated, the air-bubble will settle in the middle in both positions of the telescope. This, and the adjustment for the collimation, generally require repeated trials before they are completed, on account of the difficulty in estimating exactly half the quantity of deviation.

TO SET THE TELESCOPE PERPENDICULAR TO THE VERTICAL AXIS.

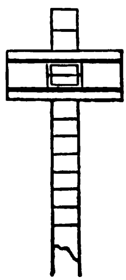
Place the telescope over two of the parallel plate-screws, and move them (unscrewing one while screwing up the other) until the air-bubble of the level settles in the middle of its tube; then turn the instrument half round upon the vertical axis, so that the contrary ends of the telescope

may be over the same two screws, and if the bubble again settles in the middle, all is right in that position; if not, half the error must be corrected by turning the screw, B, and the other half by the two parallel plate-screws, over which the telescope is placed. Next turn the telescope a quarter round, that it may lie over the other two screws, and make it level by moving them; and the adjustment will be complete.

Before making observations with this instrument, the adjustments should be carefully examined and rectified, after which the screw, B, should never be touched; the parallel plate-screws alone must be used for setting the instrument level at each station; and this is done by placing the telescope over each pair alternately, and moving them until the air bubble settles in the middle. This must be repeated till the telescope can be moved quite round upon the staff-head, without any material change taking place in the bubble.

OF THE LEVELLING-STAVES.

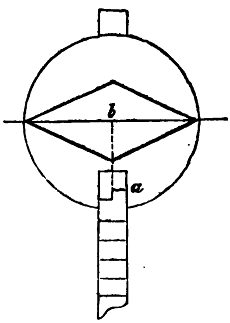
Two mahogany station-staves generally accompany the spirit-level; they consist of two parts, capable of being drawn out when considerable length is required. They are divided into feet and hundredths, or feet, inches, and tenths; and have a sliding-vane, with a wire placed across a square hole in the centre, as shown in the annexed figure; the vane being raised or lowered by the assistant until the cross wire corresponds with the horizontal wire of the telescope, the height of the wire in the vane noted on the staff, is the height of the apparent level above the ground at that place.



When both the staves are used they should be set up at equal distances on each side of the spirit-level; the difference of the heights of their vanes will be the absolute difference of level between the two stations. But when one staff only is employed, the difference between the height of the vane and the height of the centre of the telescope of the instrument will be the apparent difference of level; which, if the difference between the staff and instrument is great, requires to be corrected for the curvature of the earth and refraction; the method of computing which corrections will be shown further on.

TROUGHTON'S LEVELLING-STAVES.

These consist of three sliding rods of mahogany, each four feet long, and they are divided into feet, &c., as those which have just been described. The sliding-vane is circular, having at the lower edge a square aperture, one side of which is bevelled; and a line on the bevelled side denotes the reading of the staff. The face of the vane is made of white holly, with an inlaid lozenge of ebony, forming at once a conspicuous object, and one easy of bisection. A circular spirit-level is attached to the top of the hindermost rod, to guide the assistant in holding it perpendicular.



In levelling, the vane must be moved up or down, until the horizontal wire of the telescope bisects the acute angles of the lozenge; or, in other words, passes through its horizontal extremities, as shown in the figure.

A line on the bevelled edge at *a* (as before stated) denotes

the reading of the staff; therefore a piece equal in length to the distance, *a b*, is cut off from the bottom of the staff, or rather, the divisions commence at that number of inches above 0.

When the observation requires that the vane be raised to a greater height than four feet, the object is effected by leaving it at the top of the rod in front, and then sliding this rod up upon the one which is immediately behind it; this will carry the vane up to eight feet, and from that to twelve may be obtained by similarly sliding the second upon the third rod. In the latter steps the reading is at the side of the staff, the index division remaining stationary, and at four feet from the ground: a circumstance which affords great facility in reading off.

The Troughton staves, although exceedingly well-contrived and very portable, are liable to some objections, the principal of which is, that the observer must depend on his assistant to read the height observed; or, if he is not sufficiently intelligent to be entrusted with so responsible a duty, he is obliged, after the observation is made, to carry the staff to the observer, or wait for him to come and read off the height of the vane and register it in his field-book; thus occasioning great loss of time and uncertainty in the results, for the vane on the staff might possibly be shifted in the meantime. Also, when very dry, I have found the slides to slip down one or two tenths of an inch, notwithstanding every care on the part of the assistant to hold his staff steadily: a remedy has been found for these defects in

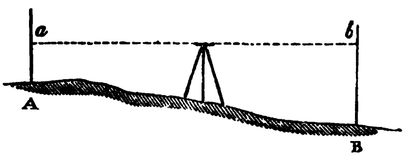
THE NEW LEVELLING-STAVES.

These have no vane to slide up and down, but the face of each staff is made broad enough to contain sufficiently

large graduations and figures, for the observer to read with certainty to the one-hundredth part of a foot, at the distance of seven or eight hundred feet, which is sufficient for most practical purposes; thus securing greater certainty and expedition in the work: for it not unfrequently happened, in using the old staves, that, when, by a succession of signals, the staff-holder had nearly brought the wire of the vane to coincide with that of the telescope, he would, in his attempt to perfect it, remove the vane further from coincidence than at first.

The newly constructed staff consists of three parts, which pack together for carriage in a neat manner; and when opened out for use form a staff seventeen feet long, jointed together something after the manner of a fishing-rod: the whole length is divided into hundredths of a foot, alternately coloured black and white, and occupying half the breadth of the staff; but for distinctness the lines denoting tenths of feet are continued the whole breadth, every half foot or five tenths being distinguished by a conspicuous black dot on each side.

Let us now see how the difference of level is ascertained, between two points, A and B, a distance we will suppose of five hundred feet. Plant the spirit-level about midway between the two stations, taking care to press its legs



firmly in the ground; draw out the eye-piece of the telescope until the cross-wires appear perfectly well defined; then directing the telescope to a levelling staff, held at one

of the stations, turn the milled-head, A, until the smallest graduations on the staff can be seen with clearness:* that these two adjustments be very carefully and completely performed, is of more consequence than is generally supposed, for upon them depends the existence or non-existence of instrumental parallax.

Having made the above adjustments perfect, bring the spirit-bubble into the centre of its glass tube, which position it must retain unmoved in every direction of the instrument; or, in other words, the bubble must indicate a true level during the time the telescope is turned completely round horizontally on its staff-head: this is accomplished by bringing the telescope successively over each pair of the parallel plate-screws and giving them motion, screwing up one while unscrewing the other to a corresponding extent, in the manner pointed for the adjustment of the theodolite, page 25.

The level being now prepared for observation, an assistant holds up the staff at A, either resting it on the ground, or, what is far better, upon a small iron tripod, which is now generally used, and is nothing more than a triangular piece of plate-iron, with its corners turned down to serve as cramps, whereby it may be steadily fixed in the ground; and with a small projection on the middle of the upper surface on which the foot of the staff is to be placed: the assistant must be careful to hold it perpendicularly. The observer now directs his telescope upon the staff, and when nearly in the right direction let him turn the clamping-screw, D, after which, by means of the slow-motion screw, E, the telescope is adjusted with greater exactness upon the staff; when the number of feet, and hundredths of a foot, are to be carefully noted, as cut by the horizontal

* We suppose the new levelling-staves to be used.

wire of the telescope, and represented by *a* in the figure, the dotted line, *a b*, representing the line of sight or visual ray. The assistant then places his staff on a tripod at B, and the observer (taking care to notice that the bubble of his level continues in the centre of its tube) directing his telescope, reads off as before. We will suppose that the reading with the staff at A was 3 feet and 9 hundredths of a foot, and that the reading with the staff at B was 7 feet and 11 hundredths; then the difference of level between the two stations is obtained by subtracting the less from the greater. The difference here is 4 feet and 2 hundredths.

The above is an example of simple levelling, when the stations not being more than six or seven hundred feet apart, and the inclination of the ground slight, one operation is sufficient. But when, from the distance or great steepness, several similar operations are necessary, it is called compound levelling, and a register or field-book is required to enter the observations in.

Let us now suppose a case of compound levelling, and the proceeding will be as follows—to ascertain the difference of level between two points, A and G, plate XVII., fig. 1.

Plant the spirit-level, as before, about midway between A and a point, B, at any convenient distance, which need not be exactly in line between those points. Then the instrument being carefully adjusted, we will suppose that when directed to A, the reading on the staff, A *a*, is 3·07 feet, and when turned to B, that it is on the staff, B *b*, 7·08 feet. The instrument being then successively placed at convenient situations between B C, C D, D E, E F, F G, let us suppose that the readings on the staves held up at A, B, C, &c., are, as entered in the field-book in the following page:—

Back.		Forward.	
A	3·07	B	7·08
B	4·03	C	9·05
C	10·00	D	1·08
D	8·02	E	5·02
E	2·10	F	7·20
F	6·09	G	2·21
	33·31		31·64
	31·64		

1·67, that G is above A.

The sum of all the back readings being greater than that of the forward ones, the latter is deducted from the former, which gives 1·67 feet as the difference of level between the points A and G.

Such is the easy process, whatever the distance or nature of the ground; whether a continued descent or of an undulating character: and if a section of the ground between the points is not required, the most convenient line for the operation may be selected; but when a section is to be made, the distances between the several stations must be carefully measured, and the rises and falls of the ground reduced to the true horizontal lengths; this reduction had better be made during the operation, in order that the column of distance in the field-book may show the horizontal ones, and thus save trouble when the section is to be drawn.

The following method of obtaining the horizontal length of a slope, will be found to answer very well for short distances. Let one end of a measuring-tape be held close to the ground at the upper station by an assistant; you then descend to the length of the tape, or less, if the slope be considerable, and elevate the other end, at the same time

drawing tight, until the stretched tape is horizontal; when a small stone being dropped, the point where it falls will be the position from which the next measurement is to commence. But for long distances, especially when the ground rises or falls with regular slopes, it will be found better to measure the length of a slope, and afterwards reduce it to the true horizontal distance by calculation. When, however, the rise or fall is very slight, the reduction may altogether be disregarded; the difference between the hypothenusal and horizontal measurements being scarcely perceptible.

The following little table will be useful in making reductions:—

Rise in Feet for One Hundred.	Reduction upon One Hundred Feet in Feet and Decimals.
1	0·01
2	0·02
3	0·05
4	0·08
5	0·13
6	0·18
7	0·24
8	0·32
9	0·40
10	0·50
11	0·61
12	0·72
13	0·85
14	0·98
15	1·14
16	1·29
17	1·45
18	1·63
19	1·82
20	1·93

When an operation of levelling is performed for the purpose of obtaining a section, the form of a field-book, as follows, will be found very convenient. We shall insert the levels as in the former field-book.

LEVELLING FIELD-BOOK.

Back.	Forward.	Distance.	Difference.		Reduced Level.	Remarks.
			Rise.	Fall.		
A 3·07	B 7·08	320	....	4·01	— 4·01	below A.
B 4·03	C 9·05	406	....	5·02	— 9·03	ditto.
C 10·00	D 1·08	240	8·92	....	— 0·11	ditto.
D 8·02	E 5·02	318	3·00	....	+ 2·89	above A.
E 2·10	F 7·20	548	....	5·10	— 2·21	below A.
F 6·09	G 2·21	625	3·88	....	+ 1·67	above A.
33·31	31·64		15·80	14·13		
31·64			14·13			
1·67			1·67			

The sign — (minus) prefixed to the 4·01 in the column of reduced levels, signifies that the point, B, is 4·01 feet below A: the same sign continues with the two following entries, showing that C is 9·03 feet, and D, 0·11 feet below A: but E we find to be 2·89 feet above A, and the sign + (plus) is used to denote that it is so.

The figures in the last column are obtained by addition or subtraction, as the case may require: for instance, we find that when our instrument is placed between A and B, that B reads 7·08.

$$\begin{array}{r l} & 7{\cdot}08 \\ \text{and A} & 3{\cdot}07 \\ \hline & 4{\cdot}01 \text{ difference — fall.} \end{array}$$

Again, between B and C the difference of level is 5·02; the ground still falling, this must be added to the 4·01, making a total fall from A to C of 9·03 feet.

From C to D there is a rise of 8·92 feet, which quantity being deducted from 9·03, brings the levelling up to 0·11 feet of the level of A; and the rise continuing to E, which is 3 feet above D, we have (by deducting 0·11 feet that D was below the level of A) the level of E 2·89 feet above A; and so on.

It is a proof that the field-book has been correctly kept, when the difference between the totals of the back and forward stations, and that between the totals of the rises and falls, agrees with the last reduced level: thus, by reference to the above example of a field-book, it will be seen that this condition is fulfilled; 1·67 appearing in the proper columns as the height of G above A.

Experienced surveyors do not usually reduce their levels as they proceed; but it is recommended for the student to reduce them in the field; as by doing so he will be able to detect any great error, as, for instance, inserting a number in the column of rises, when it ought to be placed in that of the falls; the ground showing him that he is descending instead of rising.

Referring to the terms "Back" and "Forward" Stations in the form for keeping a levelling field-book, it should be observed that, as each station becomes a forward and back station alternately, the terms back and fore relate only to the respective position as being back and forward with reference to the position of the observer. When the level

of any two points is taken, that point or station on which the first observation is made is a "back" station, and that on which the second observation is made is a "forward" station, although both may be behind the instrument, with reference to the direction in which the line is being levelled. There may be several sets of back and forward sights taken without moving the instrument; in such case, the reading of the fore sight of one becomes the reading of the back sight of the next succeeding set, and is, therefore, to be repeated in the field-book.

When a section of a line of country has been completed (for any purpose whatever), it is in most cases necessary to check its accuracy by repetition; yet in doing this it is seldom requisite to level over precisely the same line of ground, unless there is cause to suspect its general correctness, but to follow the most convenient and nearest route, and at intervals to level to some known points on the exact line of section, which will give *their* difference of level: the points thus selected are generally what are called *bench* marks, and are nothing more than marks or notches cut upon gate-posts, stumps of trees, mile or boundary stones, or any similar immoveable objects, contiguous to the lines of section, and at frequent intervals. These bench marks are made by the person who takes the section, in the first instance, and are sometimes previously determined upon. When the section is complete, their relative heights with regard to the base line, or datum of the section, become known; consequently, they may be considered as so many zero or fixed points on the line, easily recognisable, from whence any portion of the work may be levelled over again; or branch lines of level may be conducted in any direction, and the levels of such branches be comparable with those of the main line.

TO DRAW THE SECTION.

Rule a straight line, A g (plate XVII, fig. 2), to represent an horizontal line at the level of A; this is termed a *datum line:* along it, set off A b equal to 320 feet, namely, the *horizontal* distance from A to B, as entered in the field-book: from the point, b, let fall a perpendicular, and make b B = 4·01. Join A B. Take b c = 406 feet, and make the perpendicular, c C = 9·03 feet. Join B C. In the same manner proceed with the *section,* letting fall or raising perpendiculars, d D, e E, &c., according as the field-book entries carry the section below or above the datum line, A g.

In setting off on the datum line, each distance separately (as above described), you carry forward whatever error may have been made in taking any of them from the scale. To do away with this source of error, it is better to add the measured lengths together, each to the sum of those preceding it; thus obtaining the absolute length of every station from the starting point; and by setting them off in this way, the height of each will be placed on the section in its correct relative situation; and should an error be committed in marking off any point, it does not affect the rest.

If the foregoing method of reducing levels be found difficult or troublesome, on account of the introduction of plus and minus signs, they can be dispensed with, as well as the columns of "Rise" and "Fall," by proceeding in the following manner:—Assuming the starting-point to be any even number of feet high; or, what is the same thing, assume a datum line any even number of feet below the

starting-point, as 100; taking care that your choice falls upon a number greater than the number of the whole fall you are likely to experience in the operation; then from this assumed height *subtract* the reading of the forward, and to the remainder *add* the reading of the back-staff, the result will be the height of the first forward station above the assumed datum line; then from this height subtract the next forward reading, and to the remainder add the reading of the back-staff, the result will be the height of the second forward station above the assumed datum; and so on throughout the whole levelling operation. The difference between any two of the readings will be the difference of level between the corresponding points on the ground.

By way of illustration, we will reduce part of the foregoing example after this manner, and the student can then adopt whichever method he may consider the best.

Back Sight.	Forward Sight.	Reduced Levels.	REMARKS.
		100·00	Assumed datum.
3·07	7·08	7·08	
		92·92	
		3·07	
		95·99	Height of 1st former station [above assumed datum.
4·03	9·05	9·05	
		86·94	
		4·03	
		90·97	Ditto 2nd ditto ditto.
10·00	1·08	1·08	
		89·89	
		10·00	
		99·89	Ditto 3rd ditto ditto.
8·02	5·02	5·02	
		94·87	
		8·02	
		102·89	Ditto 4th ditto ditto.
2·10	7·20	7·20	
		95·69	
		2·10	
		97·79	Ditto 5th ditto ditto.
6·09	2·21	2·21	
		95·58	
		6·09	
		101·67	Ditto 6th ditto ditto.

If, after adopting the latter mode, it should be required to reduce the levels to that of the starting point as a datum, nothing more is required than to take the difference between the height thus found, and that of the assumed datum: thus, in the above example, subtracting 95·99, the height of the first forward station, from 100 (the assumed datum), we have 4·01 for its height below the starting-point: next, taking 90·97 from 100, leaves 9·03 for the quantity that the second forward station is below the level of the starting-point; and so of the rest. Or it may be done much easier after the section is made to the assumed datum, by drawing a line parallel thereto through the point, A, or any other that may be determined on: thus, the section may at once be adapted to any required datum line.

Fig. 2, plate XVII., also shows the mode of drawing a section, according to the latter way of keeping the register. *h o* represents the datum line; *h i*, *i k*, *k l*, &c., the distances from station to station; perpendicular lines, *h* A, *i* B, *k* C, &c., being drawn to *h o*; *h* A is made 100 feet (the assumed datum), *i* B, 95·99, the height of the first forward station above the assumed datum; *k* C 90·97, the height of the second forward station above datum; and so on.

It may here be observed, that when a section is made of a considerable length of ground for railway, canal, or other purposes, two scales are used, one for the horizontal distances, the other for the vertical heights and depths, which produce a caricatured representation of the country; but by making the vertical scale much larger than the horizontal one, the depths of cutting and embankment required in the execution of road, railway, or canal works, is shown with greater clearness than if both scales were equal. Civil engineers usually take 4 inches to a mile for the horizontal scale, and 100 feet to one inch for the vertical one.

LEVELLING WITH A THEODOLITE.

The use of the theodolite, as a levelling instrument, consists in taking a series of angles of elevation and depression along the line, the section of which is required. To do this, it is only necessary to set the instrument up at every spot on the line of country to be levellel, where the inclination changes, without regard to the minor inequalities of the surface, taking care that the adjustments have been carefully examined and rectified; especially those which set the line of collimation and the spirit-level attached to the telescope parallel to each other. Then set the instrument level, by means of the parallel-plate screws, as directed at page 25; and direct an assistant to go forward with a staff, having a vane or cross-piece fixed to it, exactly at the same height from the ground as the centre of the axis of the telescope. Having gone to the forward station, the assistant must hold the staff upright whilst the observer measures the vertical angle which an imaginary line, connecting the instrument and staff, makes with the horizon; the instrument and staff should then change places, the same angle should be taken back again, and the mean taken as the correct result.

The distance must then be measured, which it will be evident is the hypothenuse of a right-angled triangle; the perpendicular of which is the difference of level, to be obtained by calculation from the following

RULE. *Add together the logarithm of the measured distance and the log. tangent of the observed angle; the sum, rejecting ten from the index, will be the log. of the difference of level in feet, or as the distance was measured in.*

In this manner, by considering the surface of every principal undulation as the hypothenuse of a right-angled

triangle, the operation of levelling may be carried on with great rapidity, but with less accuracy than by the spirit-level.

Another method of applying a theodolite to the purposes of levelling, is to set up the instrument at the foot of an inclination: thus, suppose the theodolite placed at A, fig. 3, plate XVII., and the telescope elevated so that the line of sight, A B, may coincide with the vane on a staff, exactly at the same height from the ground as the instrument; suppose the staff held at B, the angle of elevation being carefully noted, the instrument must remain perfectly steady, whilst the observer is watching an assistant passing along the line with a staff, which he successively holds up at every change of inclination, as C, D, E, &c., the staff-holder raising or lowering the vane until the observer perceives the cross-wires of the telescope (or line of sight, A B) to coincide with that on the vane; the height of the staff is then read off and noted, which gives the depression of that spot of ground below the line, A B; and this being done along the whole distance, and a mark made on the ground at each spot, that the distances may likewise be measured, the undulations of the surface below the line A B, are determined, and the inclination of the line of sight being likewise obtained with the theodolite, the requisite data for drawing the section are obtained: and it will easily be seen that, when the ground is irregular, the section will be obtained with greater exactness when the stations, or points where the staff is held up, are very numerous.

After having obtained the difference of level from station to station, either with a spirit-level or theodolite, the rate of inclination of the surface may be found by dividing the distance by the difference of height; thus, if the distance be 760 feet, and the height 38 feet, 760 divided by 38 gives 20; showing the rate of inclination to be 1 in 20.

Probably sufficient has now been said, as regards the practical part of the subject, to enable a student to understand and practise all ordinary levelling operations; but one or two examples of the methods pursued by military men when taking sections for the purpose of profiling and defilading field-works, &c., may be useful.

1. We will suppose that, for some military object, it is necessary to ascertain the difference of level between the crest of the parapet, A, and the foot of the glacis, B, fig. 4, plate XVII.; and that the following implements only are at hand, namely, a 10-feet rod, two boning-staves of 3 feet, a staff of similar form, that is, with a T head, of 6 feet, and a mason's level.

Drive a picket at C, and level the top of it with the point, A, by the mason's level. Next send a man to the foot of the glacis at B, and let him hold up the 10-feet rod, against which he must slide the 6-feet staff, until the top of it, D, is found to be on a level with the boning-staves held at A and C; when it is evident that the point to which the head of the staff at D reaches along the 10-feet staff, deducting 3 feet (length of the staff at A), will be the difference of level required.

2. We will suppose that a section of a field-work is to be made by means of the same implements. Fig. 5, plate XVII.

Here it is only necessary, after the head of a picket driven at D is made level with the point, C, to cause an assistant to hold up the 10-feet rod at the foot of every slope, along which he is to slide the 6-feet boning-staff, until it appears on a level with the staves held up at C and D. The horizontal length of each slope is easily determined by resting the 6-feet staff on the level part at the bottom, taking care to hold it perpendicularly, while the 10-feet rod is applied in an horizontal position, as from *e* to *f*, *e* to *h*, &c.

Should the bottom of the ditch be too low for the long rods to reach up to the level of the staves at C and D, the level of the crest of the glacis at F may be taken, and a picket driven at G to the level of F, when the length, H O, may be observed.

With a spirit-level it would only be necessary to plant the instrument on the banquette at *f*, and hold up the regular levelling-staff at the foot of each slope, as described above.

To draw the section it will merely be requisite to rule a line, and having set off upon it the horizontal lengths of the several slopes, let fall perpendiculars from the points obtained, along which distances are to be taken corresponding with the levelling.

TABLE*

Showing the Reduction in Feet and Decimals upon 100 *Feet, for the following Angles of Elevation and Depression.*

Angle.	Reduction.	Angle.	Reduction.	Angle.	Reduction.
3° 0′	0·14	9° 0′	1·22	15° 0′	3·40
		30	1·38	30	3·64
4 0	0·25	10 0	1·52	16 0	3·88
		30	1·68	30	4·12
5 0	0·38	11 0	1·84	17 0	4·37
		30	2·01	30	4·63
6 0	0·55	12 0	2·19	18 0	4·90
30	0·65	30	2·37	30	5·17
7 0	0·76	13 0	2·56	19 0	5·44
30	0·86	30	2·77	30	5·74
8 0	0·98	14 0	2·97	20 0	6·03
30	1·10	30	3·18	30	6·33

The reduction for 100 feet (from the above table) multiplied by the number of times 100 feet measured, will give the quantity to be subtracted from the measured length of an inclination to reduce it to the horizontal distance.

* This table is formed by simply subtracting the natural cosines of the angles from the radius 100.

TABLE

Showing the Rate of Inclination of inclined Planes for the following Angles of Elevation.

Angle.	One in	Angle.	One in	Angle.	One in
0° 15′	228	3° 30′	17	7° 0′	8
0 30	114	3 45	16	7 30	7¼
0 45	76	4 0	15	8 0	7
1 0	56	4 15	14	9 0	6½
1 15	46	4 30	13	10 0	6
1 30	38	4 45	12	11 0	5¾
1 45	32	5 0	11½	12 0	5½
2 0	28	5 15	11	13 0	5
2 15	26	5 30	10½	14 0	4½
2 30	23	5 45	10	15 0	4
2 45	21	6 0	9½	16 0	3¾
3 0	19	6 30	9	17 0	3½
3 15	18	6 45	8½	18 0	3¼

TRACING CONTOUR LINES.

Mention has already been made of the contour method of delineating the features of ground, but an explanation of the way in which the contours are to be traced was necessarily referred to the subject of levelling. I shall now give the process in the words of Captain Frome, R.E.:—

"The method of tracing these contours on the field is simply thus:—Bandrols or long pickets are first driven, one at the top and another at the bottom of such slopes as best define the ground, particularly the *ridge-lines* and *water-courses*. Should no such *sensible lines* exist, they must be placed at about equal intervals apart, regulated by the degree of minutiæ required, and the variety in the undulations of the surface of the ground. A short picket being driven on the level of the intended upper (or lower) line of contours, and in line between two of the bandrols,

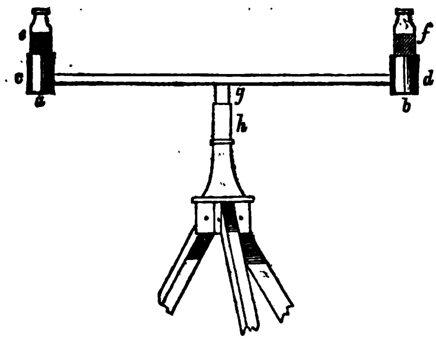
the level is placed so as to command the best general view of this first line, and adjusted; care being taken that its axis is not so low as to cut the ground below the picket (or so high as to be above the top of the levelling-staff, if the lower contour is the first traced); the staff is then placed at this picket, and the vane raised or lowered till it is intersected by the cross-wires of the telescope; the staff, with the *vane kept to this height,* is then shifted to another point on about the same level, and in the line between the next two pickets, and *the staff itself* moved up or down the slope till the vane again coincides with the cross-wires, at which spot another picket is driven. This operation is continued till it is necessary to move the level to continue the same upper contour line, when (the staff being placed at one of the pickets just driven) the vane is again raised or lowered to suit the new position of the axis of the instrument, and then kept at this height as before for the continuation of the line. To trace the next contour-line, it is merely necessary to raise the *vane* on the staff, five or whatever number of feet may be the vertical distance determined upon, and proceed as before. When the level itself has to be moved to lower ground, it must be so placed that its axis will cut the ground above one of the pickets of the line just marked out, and the same quantity of five feet, added to the reading of the staff at this picket, will give the height of the vane for the next lower horizontal line.

"The use of driving all these pickets, marking out the contours nearly in the same line down the slopes, becomes evident when they are to be laid down on the plan; the places of the original bandrols or long pickets being fixed, with reference to each other, it is only necessary to measure between them, entering the distances on these lines, with the off-sets to the right or left, to the different short pickets marking the horizontal lines."

This process of tracing contour lines, by means of the *spirit-level*, occupies necessarily much time, and is only suited to the object of obtaining an exact delineation of ground, to a limited extent, for engineering purposes; and a moment's consideration will convince any one that it is unsuited to the business of the *military surveyor*, whose object in general is to give a rapid delineation of portions of country, more or less extensive, with sufficient accuracy for ordinary military objects, instead of working in the slow and methodical manner of an engineer, when making a plan of ground with a view to constructing upon it a fort or a fortress.

French engineers, as I am informed, make little use of the spirit-level in tracing contours, for, the distances being short, a less accurate instrument answers the purpose sufficiently well. The *water-level*, which is a very simple one of their invention, is suitable for tracing contours, as well as performing other ordinary levelling. It requires no adjustments, may be made for a few shillings, and in short distances no great error can be made when using it, as may happen with a badly-adjusted spirit-level, the horizontal line being adjusted by the law of fluids; it has, moreover, this great advantage in the eyes of military men, that any common workman may construct it. Captain Frome mentions that he had one made by an ironmonger in Chatham, which, being tried against a very good spirit-level, was found to give a perfectly satisfactory result.

"*a b* is a hollow tube of brass, about half an inch in diameter, and about three feet long; *c* and *d* are short pieces of brass tube of larger diameter, into which the long tube is soldered, and are for the purpose of receiving the two small bottles, *e* and *f*; the ends of which, after the bottoms have been cut off by tying a piece of string round them when heated, are fixed in their positions with putty or white lead;

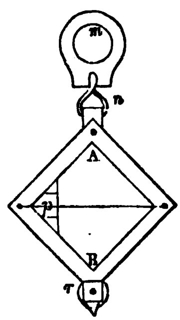


the projecting short axis, *g*, works (in the instrument from which the sketch was taken) in a hollow brass cylinder, *h*, which forms the top of a stand used for observing with a repeating-circle; but it may be made in a variety of ways, so as to revolve on any light portable stand. The tube, when required for use, is filled with water (coloured with lake or indigo), till it nearly reaches to the necks of the bottles, which are then corked for the convenience of carriage. On setting the stand tolerably level by the eye, these corks are both withdrawn, which must be done carefully and when the tube is nearly level, or the water will be ejected with violence; and the surface of the water in the bottles, being necessarily on the same level, gives a horizontal line in whatever direction the tube is turned, by which the vane of the levelling-staff is adjusted."

A more recent invention of our clever neighbours, the French, is the "Reflecting-level," by Colonel Burel, of the Corps du Génie.

"The principle upon which this instrument acts is implied by its name. In a plane mirror the rays are reflected as though they diverged from a point *behind* the mirror, situated at precisely the *same distance in rear of its surface as the object itself is in front*. If the mirror be vertical *the eye and its image are on the same horizontal*

line; and any object coinciding with these is necessarily on the *same level.* It appears, then, only requisite to ensure the verticality of a small piece of common looking-glass, set in a frame of wood or metal, to be able, without further assistance, to trace contour lines in every direction, or to take a section on any given line. The mirror, A B, is only one inch square, fixed against a vertical plate of metal, weighing about one pound, and suspended from a ring, *m,* by a twisted wire, *n;* so that it may hang freely, but not turn round on its axis of suspension. It can either be used for sketching in the field, being held by this ring at arm's length; or fixed for greater accuracy in a frame which fits upon the top of the legs of a theodolite, with a bar of metal like a bent lever, pressing so slightly against it from below that it may check any tendency to oscillation, and at the same time not prevent the mirror from adjusting itself by its own weight.



"The required verticality of the plane of the mirror is thus ascertained:—a level spot of ground is chosen, where it is suspended in its frame (the simple-level, without the frame, only appears in the figure given above), on any temporary stand, placed forty or fifty yards from a wall; and the prolongation of the line of sight, *from the eye to its image,* coinciding with a fine silk thread across the centre of the mirror, is marked on the wall, which is visible through a small opening, *p,* in the metal frame. The mirror is then turned round, and the observer, placed between it and the wall, with his back to the latter, notes the spot when the *image of his eye* coincides with the reflected wall *above or below the former mark.* The mean distance between these two points is assumed and marked; and, by turning a screw

at r, the centre of gravity of the mirror is altered until the image of the eye, coinciding as before with the silk thread, agrees also with this central mark on the wall. It would, perhaps, be a better plan to send an assistant some distance behind the mirror, with a levelling-staff, the vane of which could be raised or lowered to coincide with the line of sight; on reversing the mirror (the staff remaining stationary), the vane would be again moved, until its reflected zero mark is cut by the thread, on a level with the image of the eye; and, finally, the mirror adjusted by the screw, to the mean between these two heights: this method admits, apparently, of greater nicety than a chalk-mark on a rough wall.

"The reflecting-level is not generally known in this country; but for many purposes it is superior to any other description of instrument, particularly for tracing contour lines on the ground in a military sketch. It is peculiarly simple in its construction; is easily managed; easily adjusted; is not liable to have this adjustment deranged, or to be injured by a fall; is, from its size, more portable than any other instrument, and can be used either held at arm's length, or *at a distance of several feet;* in which position the length of the line of sight ensures the greatest accuracy."

Such is the opinion of Captain Frome. But I shall extract from the second volume of Professional Papers of the Royal Engineers, a portion of the Report of a Committee of French Engineers upon this instrument:—

Water-level compared with the Reflecting-level.

"The water-level is uncertain, troublesome in confined places and rugged ground. Its form renders it sensible to the least wind or sudden jerk; its fall may even destroy it, and render null many of the preceding observations. One person is always required to carry it; and continual

attention must be directed to preserve the level; and the line of sight seldom or never exceeds three feet.

"The reflecting-level, on the contrary, from its size, is not affected by the wind, or being accidentally touched. Its fall does it no injury; it is easily carried, and may be used without a stand, by hanging it from a tree, at a window, or, in a word, without any trouble whatever. Little space is required for using it, as the length of the line of sight is optional, and may be as much as twenty-six feet. Again, it may be made of the commonest materials, such as hard wood, if brass, silver, or platinum cannot be obtained.

"If it be true that the reflecting-level has so many advantages over the water-level, when they are both placed on the ordinary tripod or stand, its superiority will be still more displayed in such hasty observations as may be necessary to an army in the field, where it will be sufficient to hold it at arm's length, and equal correctness will be obtained as with the water-level, which requires more time and greater care. Why is this? We know that a pendulum will oscillate a long time when suspended from a fixed point; but, if it be attached to another which also oscillates in proportion to its length, the oscillations of the pendulum, checked by those of the support, are soon shortened and annihilated: any one may verify this fact, by suspending a weight from the finger, and swaying it gently as it oscillates.

"To level in this manner, the instrument must be held at arm's length, and at the same height as the eye. Take advantage of one of its short moments of repose, which are nearly periodical, and make the observation which, though furtive, will be more correct than might be expected, since in repeating it immediately afterwards, by a second and third *coup-d'œil*, it will be seen that these last results differ very slightly from the first.

"This precision may be augmented by suspending the

instrument from an arm, at the end of a short staff, set up to the requisite height.

"In this manner, observations may be taken in every direction without a stand or choice of station, only stopping to make the necessary note; and it is most convenient in levelling gently undulating ground, or in filling up the details between two horizontal contours.

"Thus, in taking the height of several hills, varying from 190 to 260 feet of elevation, which had been previously levelled, it was found that the greatest errors did not exceed six inches; so much for its correctness: and for celerity, upwards of sixty acres have been levelled in a single day by horizontal contours, distant only one yard from each other, and with the assistance of a single aid to carry the staff."

Another little instrument which, from its portability, simplicity, and the ease with which it is made, viz., the "Clinometer" (noticed at p. 76), must not be forgotten as an aid in tracing contour lines.

I have been careful to draw attention to the more simple levelling instruments, as a spirit-level is both too heavy and costly, to form part of a staff or engineer-officer's field equipment.

I understand that Colonel Colby, R. E., who now so ably directs the Trigonometrical Survey of the British Islands, has caused the contour system to be practised in delineating the ground, and I make no doubt of this method becoming general whenever a very exact representation of ground is required; but, for the ordinary sketches and plans of the military surveyor, the system can neither be exercised with sufficient rapidity, nor (so far, at least, as I may pretend to offer an opinion on the matter) is such great precision necessary.

SECTION XIX.

THEORY OF LEVELLING — TERRESTRIAL REFRACTION AND CURVATURE—LEVELLING BY THE MOUNTAIN BAROMETER —TO DETERMINE ALTITUDES BY THE DIFFERENT TEMPERATURES AT WHICH WATER BOILS.

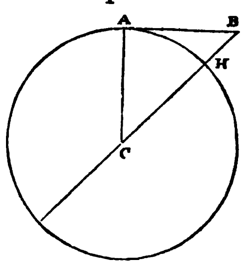
LEVELLING is the art of finding how much higher or lower any given point on the surface of the earth is, than another given point on the same surface; or, in other words, the difference of their distances from the centre of the earth.

Those points are said to be *level* which are equidistant from the centre of the earth; the art of levelling, therefore, consists,

1st. In finding two or more points that shall be in the circumference of a circle, whose centre is that of the earth.

2nd. In comparing the points thus found with other points, in order to ascertain the difference in their distances from the centre of the globe.*

Let the circle in the annexed figure represent the earth, C its centre, and A B a tangent. Then A B represents the apparent, and A H the true, level; the points, A and H, being equidistant from the centre, C. When we say that A B represents the apparent level, we mean that it is the line which a spirit-level, or any other mode of levelling, would trace,



* The figure of the earth is not that of a perfect sphere; being somewhat flattened at the poles. The length of the *equatorial* diameter is 7924 miles, and that of the *polar* diameter 7898 miles. For our present purpose, it is sufficiently correct to consider it as a sphere.

forming a tangent to the earth's surface. Hence the difference between the true and apparent level is expressed by H B. Now, the circumference of the globe being nearly, in round numbers, 24,000 miles, the difference between the true and apparent level of any two points, as A and H, in that circumference, is scarcely perceptible when their distance from each other is less than 1000 feet. For instance, the difference in a distance of one chain, or 66 feet, is ·000104. In practice, therefore, no correction is applied during ordinary levelling operations for less distances than 1000 feet.

The rule for finding H B, whatever the distance of A H, is deduced from the Geometrical theorem, that the rectangle, $2\,C\,H + H\,B \times H\,B$, is equal to the square of the tangent, A B; hence, $2\,C\,H + H\,B : A\,B :: A\,B : H\,B$. But, at ordinary levelling distances H B may be considered as nothing when compared with the diameter of the earth. Also, A H may be taken as equal to A B. Then, $2\,C\,H : A\,B :: A\,B : H\,B$; or $\frac{A\,B^2}{2\,C\,H} = \frac{A\,H^2}{2\,C\,H}$ very nearly. By which it appears, that the difference between the true and apparent level is equal to the square of the distance between the stations, divided by the diameter of the globe. It is, therefore, always proportional to the square of the distance.

The mean diameter of the earth being nearly 7916 miles, if A H be considered as one mile, then $\frac{A\,B^2}{2\,C\,H} = \frac{1}{7916}$ of a mile, or 8·004 inches. At two miles, it is four times that quantity, or 32·016 inches; at three miles, it is nine times that quantity, or 72·036; and so on, increasing in proportion to the square of the distance. It is convenient to reject the decimal ·004, and assume the difference between the

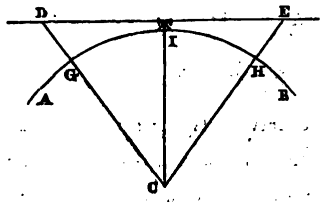
true and apparent level for one mile to be exactly eight inches, or two-thirds of a foot. We then obtain the following form for computing the correction of level in feet due to the curvature of the earth, for distances given in miles, which may easily be remembered:—

$$\text{Correction} = \frac{2\ D^2}{3}$$

D being the distance in miles. Or, in other words—*Two-thirds of the square of the distance in miles will be the amount of the correction in feet.*

The following is an explanation of the principle upon which we proceed when we place the spirit-level mid-way between the two stations, and consider the difference of the readings on the levelling-staff, as showing the true difference of level between the two stations.

Suppose it were required to find the difference of level between two points, G and H, in the adjoining figure; let A B represent a portion of the earth's surface, C the centre, and C G, C I, and C H, radii of the earth. Now, a spirit-level being set up and adjusted at I, an observer looking through the telescope would see objects in the direction of the horizontal line, D E, only, and a staff held upright at H would be read off in the point, E, on the horizontal line; but this point is higher than the true level, by the distance, H E, which is the correction for curvature due to the distance, I H (see page 237): if that quantity be subtracted from the reading of the staff, the remainder will show the difference of level between the points, I and H. If the same process be gone through, by holding a staff at G,



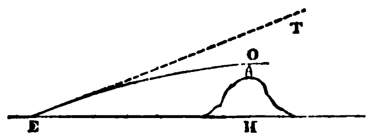
then the difference of level between G and I will also be ascertained, which, being compared with the former difference will show how much higher one of the points, G or H, is above the other; but it must be evident that, if G and H be equally distant from I, the horizontal line, D E, being a tangent at the middle point, I, must cut the staff at D on the same level with the point, E; that is, C D is equal to C E, therefore D and E are level points, being equidistant from the centre of the earth; and, if the reading of one staff above the ground is greater than the reading of the other, the difference will at once show the variation of level between the points where the staves were held, viz., G and H: the effect of curvature is thus removed by *simply placing the instrument mid-way between the station-staves.* The effects of the atmospheric refraction will likewise be done away with in the same process, because it will affect both observations alike, unless under peculiar circumstances of the weather, &c., over which the observer has no control.

The student will observe that, should he have occasion to perform a levelling operation in which his spirit-level will be placed at one of the stations instead of standing mid-way between them, and if great exactness is required, he must apply the proper corrections for curvature and refraction to all distances exceeding 1000 feet.

TERRESTRIAL REFRACTION AND CURVATURE.

On all occasions, when from the distance between two stations, in levelling, a correction becomes necessary on account of *curvature*, a second correction is essential for *refraction.* The effect of refraction is to cause all objects, when viewed from a distance, to appear higher than they really are.

Let E be the place of an observer's eye, E H an horizontal line, and O an object on the summit of a distant hill, O, E, and H being in a vertical plane.



Then, if the rays of light proceeded from the object, O, to the eye at E in a straight line, the object would appear in its true place at O, and O E H would be the angle of elevation (considering E O as a right line); but the rays in passing through the atmosphere are continually attracted downwards from a rectilinear direction, by which means the object is seen in the direction, E T, which is supposed to be a tangent to the curve at E, and, therefore, the apparent or observed elevation is the angle, T E H; and the angle, T E O, or rather the angle comprehended by T E, and a right line from O to E, will be the refraction.

This refraction, which is called the *terrestrial,* to distinguish it from that which affects the altitudes of heavenly bodies, is not constant at the same elevation and distance, but is found to vary with the changes in the atmosphere, as heat, a different density, moist vapours, &c. &c. At the distance of eight or ten miles it is sometimes no more than about thirty seconds, but in particular states of the air we find it amount to upwards of two minutes.

In all surveys where great accuracy is required, corrections for curvature and refraction should be made whenever the distances of observed objects exceed 1000 feet.

The amount of refraction is estimated in various ways; some writers allow 1-10th of the distance observed, expressed in degrees of a great circle; others, 1-11th,

1-12th, and 1-14th; but the mean, or 1-12th, has been most generally used.

The following mode will be found sufficiently accurate for reducing the observed angle:—

Divide 1-12th of the distance between the objects by 101·42 (the number of feet answering to one second of a degree), the quotient will give the number of seconds contained in that distance, which must be taken from the observed angle.

EXAMPLE.

The distance being 47,520 feet (9 miles), and the angle of altitude 1° 40′ 20″, the correction will be as follows:—

$$47520 \div 12 = 3960 \div 101{\cdot}42 = 39''$$

Observed angle	1°	40′	20″
Correction for refraction .	0	0	39
Corrected angle	1	39	41

Or the correction for refraction may be obtained thus:— Take 1-9th of the square of the distance in miles for the number of feet. Suppose the distance 9 miles, as above, then 9 feet is the allowance for refraction; for $9 \times 9 = 81 \div 9 = 9$. Which will be found to correspond with 39″, deducted from the observed angle.

When 2-3rds of the square of the distance in miles are taken for the number of feet on account of curvature, 1-6th of such number of feet will give the allowance for refraction. Refraction is always a *minus* quantity: curvature may be either plus or minus, according as the observed object is elevated or depressed.

Let A and B represent two stations, distant from each other 9 miles, with observed and corrected angle as above.

Calculation with corrected angle,

Log. of distance A B, 47,520 feet	4·6768764
Log. tangent of corrected angle . .	8·4624704
	3·1393468

3·1393468 =	1378·3
Add curvature	54
Total height	1432·3

Calculation with angle as observed = 1° 40′ 20″

Log. A B	4·6768764
Log. tangent of observed angle .	8·4652947
	3·1421711

3·1421711 =	1387·3
Correction of curvature and refraction for 9 miles, viz., 9 × 9 = 81 × $\frac{2}{3}$ = 54, or curvature, from which $\frac{1}{6}$, or 9, is deducted for refraction, leaving 45.—(See Table.)	45
Total height . . .	1432·3

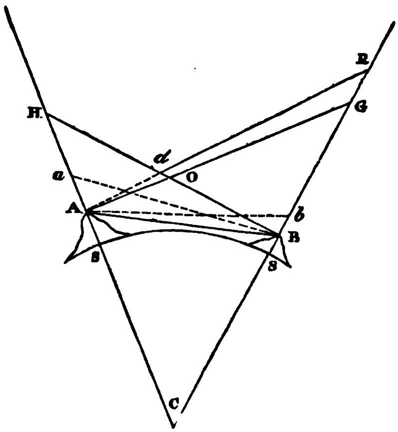
TABLE

For Curvature and Refraction from 1000 *to* 63,360 *feet, or* 12 *miles.*

Miles reduced to Feet.		Correction in feet and decimals for curvature and refraction.	Miles reduced to Feet.		Correction in feet and decimals for curvature and refraction.
Miles.	Feet,		Miles.	Feet.	
	1000	02	4	21120	8·89
¼	1320	·03	4¼	22440	10·03
	1600	·05	4½	23760	11·25
	2000	·07	4¾	25080	12·53
½	2640	·14	5	26400	13·89
	3000	·18	5¼	27720	15·31
¾	3960	·31	5½	29040	16·80
	4500	·40	5¾	30360	18·36
1	5280	·55	6	31680	20·0
	6000	·71	6¼	33100	21·70
1¼	6600	·86	6½	34320	23·47
	7000	·96	6¾	35640	25·31
1½	7920	1·25	7	36960	27·22
	8500	1·42	7¼	38280	29·20
1¾	9240	1·70	7½	39600	31·25
2	10560	2·22	7¾	40920	33·36
	11000	2·40	8	42240	35·55
2¼	11880	2·81	8¼	43560	37·81
2½	13200	3·47	8½	44880	40·14
2¾	14520	4·20	8¾	46200	42·53
3	15840	5·0	9	47520	45·0
	16000	5·1	9¼	48840	47·53
	16500	5·26	9½	50160	50·14
3¼	17160	5·40	9¾	51480	52·81
3½	18480	6·8	10	52800	55·55
	19000	7·16	11	58080	67·22
3¾	19800	7·81	12	63360	80·0

The allowance made here for refraction of 1-12th may be considered as sufficiently exact for ordinary occasions: when extreme accuracy is required, the precise amount of refraction must be ascertained at the time of observation, in the manner practised during the great trigonometrical survey by Mr. Dalby and others, which was thus:

Let A and B be two stations, S S the intercepted or corresponding arc of the earth's circumference, C the centre of the earth; A G, B H, the horizontal lines at A and B, drawn to meet C G, C H.



An instrument being at each of the stations, A and B, the reciprocal observations are made *at the same instant of time,* which is determined by means of signals or watches, previously regulated for that purpose; that is, the observer at A takes the depression (for example) of B, while the other person at B observes the depression of A.

If *a* and *b* represent the apparent places of the objects A and B, the angle *b* A B is the refraction at A, and *a* B A that at B; therefore, half the sum of the angles will be the refraction, if we suppose it equal at each station.

In the quadilateral, A O B C, the angles at A and B are right ones, therefore the sum of the other two angles at O and C are equal to two right angles, and consequently the angles, O A B, O B A, are together equal to the angle C, or arc S S; therefore, if the sum of the two depressions or angles, H B *a* + G A *b*, be taken from the sum of the angles H B A + G A B, or the angle C, the remainder is the sum of both refractions or angles, *a* B A + *b* A B; therefore *half the difference between the sum of the two depressions and the contained arc,* S S *(or angle,* C*), is the refraction.*

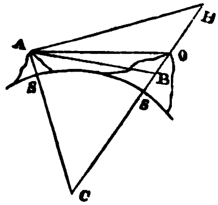
If one of the objects (B), instead of being depressed, is elevated, suppose to the point R, then the sum of the angles, *d* A B + *d* B A, will be greater than the sum, O A B + O B A (or angle, C), by the angle of elevation, R A G; but if from the sum, *d* A B + *d* B A, we take the depression, H B *a*, there will remain *d* A B + *a* B A, the sum of the two refractions: therefore, *if the depression be subtracted from the sum of the contained arc and elevation, half the remainder is the refraction in the case.*

It is almost unnecessary to remark that the distance between the places of observation, A and B, should be known sufficiently near to give the contained arc, S S, true to a very few seconds of a degree; the refraction, however, is generally too minute to be of consequence in the operations with a common theodolite, which are usually confined to moderate distances.

Mr. Dalby's illustration of the method of ascertaining the allowance to be made for curvature may be useful to the student: I shall, therefore, transcribe it.

Let A be the place of the instrument, O an object on a distant hill, C the centre of the earth, C S = C S, the earth's radius, S S, the contained arc of the earth's circumference, and A H the horizontal line, meeting C S produced; the

angle, C A H, being a right one. Make C B = C A, then the points A and B are the same height above the earth's surface, and B O will be what the object, O, is higher than the station, A. Now, suppose the observed depression of the object, O, to be 2′ = the angle, H A O, and its distance 17230 yards = A B, or the arc,



S S; then, taking 69 1-6th miles = 1 degree, we have 69 1-6th × 1760 : 60′ :: 17230 : 8′·5 nearly the arc S S, or angle, C. And because the triangle, A B C, is isosceles, the angle, B A C + ½ angle, C, is equal to a right one; but the angle, B A C + B A H, is also a right one; therefore, B A H = ½ angle, C = 4′·25; and allowing ·75 of a minute for the effect of refraction, we have 2′ + ·75 = 2′·75 the depression, H A O, corrected for refraction: therefore, B A H − H A O = B A O, or 4′·25 − 2′·75 = 1′·5 angle, B A O; whence (supposing A B O to be a right angle), it will be radius : tangent 1′·5 :: 17230 (A B) : 7·52 yards = B O, or what the object, O, is higher than the station, A.

Hence it appears that, when two objects (A and B) are on the same level, or at equal distances from the centre of the earth, the true angular depression of one below the horizon of the other will always be equal to half the number of degrees in the arc contained between them, supposing the earth to be a sphere.

The correction, ·75 of a minute, is between 1-11th and 1-12th of the contained arc; in some publications, however, we find 1-10th has been adopted, and others 1-14th; but neither can be depended upon as very correct.

This example is sufficient to point out the method of computation when the object, O, is below the point, B, or above the horizontal line, A H.

LEVELLING BY THE MOUNTAIN BAROMETER.

The barometer is an instrument for measuring the pressure of the atmosphere, and elasticity of the air, at any time. It is commonly made of a glass tube, nearly three feet long, close at one end, and filled with mercury. When the tube is full, by stopping the open end with the finger, then inverting the tube, and immersing that end into a bason of quicksilver, on removing the finger from the orifice, the fluid in the tube will descend into the bason, till what remains in the tube be of the same weight with a column of the atmosphere, which is commonly between 28 and 31 inches of quicksilver; leaving an entire vacuum in the upper end of the tube. For, as the upper end of the tube is quite void of air, there is no pressure downwards but from the column of quicksilver; and therefore, that will be an exact balance to the counter-pressure of the whole column of atmosphere, acting on the orifice of the tube by the quicksilver in the bason.

The upper part of the tube has a graduated scale attached to it, furnished with a vernier, reading commonly to one-hundredth of an inch; but in the best barometers it should read to the five-hundredth part of an inch. Again, this scale is variously graduated: in ordinary barometers only between the heights 27 and 31 inches, while such as are intended for measuring the greatest altitudes—as of the Himalaya Mountains for instance—should be graduated as low as 16 inches. By means of the scale and vernier the height of the mercury in the tube can be accurately measured, by observing the division that is tangential to the surface of the fluid.

Mountain barometers have always marked upon them such readings as these:—

N P, or neutral point	29·48
Capacity	$\frac{1}{72}$
Temperature	55°

Of these, capacity indicates the ratio between the diameter of the tube and the diameter of the cistern; which is usually obtained by trial. A certain quantity of mercury is first poured into the tube, which it fills to the height, say of 14·4 inches: this same quantity is then transferred to the cistern, and found to rise to ·2 inches. The capacity is, therefore, as 14·4 to ·2, or 72 to 1.

The *neutral point* denotes the height at which the mercury stood in the tube above the zero mark of the cistern when the barometer was made: the difference between the observed reading of the barometer and the "*neutral point*" is to be diminished in the proportion of the "*capacity,*" and the remainder applied to the observed reading, to be added when it is above the standard (N P), and subtracted when below. This is termed correction for capacity, and must be made whenever very great accuracy of measurement is required.

Temperature 55° is the generally assumed mean temperature of the air, as a basis for calculation.

Torricelli, who invented the barometer in the year 1643, soon discovered that upon ascending a hill the quicksilver fell in the tube—obviously because the column of air supporting it was shortened thereby; and this observation was, not long after, applied to the measurement of heights. But on account of the great difference of temperature, in low and elevated situations, corrections are necessary to render the results from barometrical observations, satisfactory. Before Monsieur De Luc (upwards of a century after Torricelli's discovery) began his experiments with the barometer, a mean of the two temperatures shown by the thermometer attached to the barometer, and the heights

of the mercury in the barometer, at the bottom and top of a hill, were thought sufficient to determine its height. M. De Luc, however, found that an additional or detached thermometer was also necessary (see *Récherches sur les Modifications de l'Atmosphère*); and this was subsequently confirmed by the experiments of General Roy and Sir G. Shuckburgh.

There are various experiments by which the real altitude which corresponds to any given height of the mercury may be deduced: the readiest is that which results from the known specific gravity of air, with respect to the whole pressure of the atmosphere on the surface of the earth. The investigation is thus given at vol. ii. p. 261, "Hutton's Mathematics," in accordance with the law, that, when the elevation increases in an arithmetical ratio, the weight or density of the atmosphere, and, consequently, the height of the mercurial column, diminish in a geometrical ratio:—

"Because the terms of an arithmetical series are proportional to the logarithms of the terms of a geometrical series, different altitudes above the earth's surface are as the logarithms of the densities, or the weights of air, at those altitudes.

"So that, if D denote the density at the altitude A,

and d denote the density at the altitude a;

then A being as the log. of D, and a as the log. of d, the difference of alt. $A - a$ will be as the log. D − log. d, or log. $\frac{D}{d}$.

And if $A = 0$, or D the density at the surface of the earth; then any altitude above the surface, a, is as the log. of $\frac{D}{d}$.

"Assume h, so that $a = h \times \log. \frac{D}{d}$, where h will be of one constant value for all altitudes; and, to determine that value, let a case be taken in which we know the altitude a,

corresponding to a known density, d; as, for instance, take $a = 1$ foot, or 1 inch, or some small altitude; then, because the density, D, may be measured by the pressure of the atmosphere, or the uniform column of 27,600 feet, when the temperature is 55°: therefore 27,600 feet will denote the density, D, at the lower place, and 27,599 the less density, d, at 1 foot above it; consequently, $1 = h \times \log.\frac{27600}{27599}$; which, by the nature of logarithms, is nearly $= h \times \frac{\cdot 43429448}{27600} = \frac{h}{63551}$ nearly; and hence, $h =$ 63551 feet; which gives, for any altitude in general, this theorem, viz., $a = 63551 \times \log.\frac{\mathrm{D}}{d}$,

or, $a = 63551 \times \log.\frac{\mathrm{M}}{m}$ feet $= 10592 \times \log.\frac{\mathrm{M}}{m}$ fathoms; where M is the column of mercury, which is equal to the pressure or weight of the atmosphere at the bottom, and m that at the top of the altitude, a; and where M and m may be taken in any measure, either feet or inches, &c.

"Note, that this formula is adapted to the mean temperature of the air, 55°. But for every degree of temperature different from this, in the medium between the temperatures at the top and bottom of the altitude, a, that altitude will vary by its 435th part;* which must be added when that medium exceeds 55°, otherwise subtracted.

"Note, also, that a column of 30 inches of mercury varies its length by about the $\frac{1}{320}$ part of an inch for every degree of heat, or rather $\frac{1}{9600}$ of the whole value.†

* Air expands about $\frac{1}{435}$ of its bulk for every degree of Fahrenheit.—Hutton.

According to the experiments of Dr. Dalton and M. Gay Lussac, a volume of air dilates $\frac{1}{480}$ of the volume which it occupied at 32° for every degree of Fahrenheit's scale.

† Recent experiments give $\frac{1}{9742}$, instead of $\frac{1}{9600}$.

"But the formula may be rendered much more convenient for use, by reducing the factor 10592 to 10000, by changing the temperature proportionally from 55°; thus, as the difference 592 is the 18th part of the whole factor, 10592; and as 18 is the 24th part of 435, therefore the corresponding change of temperature is 24°, which reduces the 55° to 31°. So that the formula is, $a = 10000 \times \log. \frac{M}{m}$ fathoms, when the temperature is 31 degrees; and for every degree above that, the result is to be increased by so many times its 435th part.

"Taking, instead of the logarithms, the first term of the logarithmic series, we have $55000, \frac{B - b}{B \times b}$ for the altitude in feet: B and b being the heights of the barometrical columns observed at the bottom and top of the hill. This formula is for the mean temperature, 55°, and is easily remembered, because the effective figures of the coefficient are also 55. The reductions for any other temperature are the same as the logarithmic rule."

The method of using the mountain barometer is as follows:—When not wanted for use, the mercury is forced up nearly to the top of its tube by means of a screw acting against the leathern bag which serves as a reservoir for the fluid. The instrument is carried in an inverted position, the cistern end being kept always above the horizontal, at an angle of at least 45°. When required for an observation, turn the bottom screw till it ceases to act upon the bag, gently reverse the barometer, suspend it vertically by means of a gimlet inserted in a tree or otherwise; the index is then moved till its edge is a tangent to the surface of the mercury. Observe then:—

First. The height of the barometer at the lower station, with the temperature of the mercury, by means of a

thermometer attached to the barometer, and also the temperature of the air in the shade by a detached thermometer.

Secondly. Do the same at the upper station, reducing the mercury to a common temperature, by increasing the colder or diminishing the warmer by $\frac{1}{9600}$ part of the height for every degree of difference between the two.

Thirdly. Take the difference of the logarithms of the heights of the barometer thus corrected, removing the decimal point four places more towards the right hand, the figures on the left will then be fathoms.

Fourthly. Correct the number last found for the difference of temperature of the air, by taking half the sum of the two temperatures for the mean; and for every degree which this differs from the temperature 31°, take so many times the $\frac{1}{435}$ part of the fathoms above found, and add them if the mean temperature be above 31°, but subtract them if it be below 31°; and the sum or difference will be the true altitude in fathoms; which, being multiplied by 6, will give the altitude in English feet.

Example.—Taking Hutton's formula $a = 1000 \times \frac{M}{m}$ fathoms:—

"Barometers.	Thermometers.	
	Attached.	Detached.
29·98	63°	62°
26·17	47	45
	Diff. 16	2) 107
		Mean . . $53\frac{1}{2}$
		Standard . 31
		Diff. . $22\frac{1}{2}$

9600 : 16 :: 29·98 : 0·05
Correction 0·05

$M = 29·93$ log. 1·4761067
$m = 26·17$ log. 1·4178037

Dif. 0·0583030

Approximate height = 583·030 fathoms.
435 : 22½ :: 583·030 : 30·157
30·157

The altitude sought is 613·187 fath. = 3679·122 feet."

"The observed differences of temperature of the attached and detached thermometers constitute, with the difference of height in the mercurial column, the principal elements required to obtain the relative altitude of two or more stations. But in addition to these data, other elements, such as the increase of gravitation from the equator to the poles, hygrometric changes in the atmosphere, periodical oscillations in its density, and other causes, combine to influence the results. Complex investigations, unsuited to the scope of this treatise, have been made by Laplace, Prony, F. Baily, and others, with the view to embrace the action of these phenomena in one general formula suited for purposes of computation. Their investigations have led to such accurate results that, under favourable circumstances of the atmosphere and of locality, barometrical observations can be expected to give results nearly as accurate as those obtained by trigonometrical operations." *(Williams's Geodesy.)*

When the utmost degree of accuracy is sought, it has been recommended that observations should be made at the same moment at both stations—requiring, of course, two observers and two barometers; but great care must be

taken that both instruments, and also the thermometers, are alike; namely, that they agree when together in all states of the air. It is also necessary that the specific gravity of the mercury be well ascertained, because it is not equally pure in all barometers, which is the principal reason why different results are so frequently obtained from observations made with different barometers at the same stations. Other circumstances, not generally known, may contribute to such disagreement: thus, Mr. Ramsden proved, by experiments, that the quicksilver in barometer tubes made of different sorts of glass will be suspended at different heights. Looking at all these considerations, it is, perhaps, doubtful whether greater accuracy may not be obtained by a single observer, making his second observation as quickly as possible after the first; especially if the distance between the stations is short, and provided the atmosphere is undergoing no change at the time.

The following table, for determining altitudes by the barometer, was computed by Samuel B. Howlett, Esq., chief draftsman, Ordnance, from a formula given by Francis Baily, Esq.

TABLE FOR DETERMINING ALTITUDES BY THE BAROMETER.

Computed by Samuel B. Howlett, *Chief Draftsman, Ordnance, from the formula given by* F. Baily, Esq.

Thermometers to the Barometers.			Thermometers in the open air.								Latitude of the place.	
D.	B.		S.	A.	S.	A.	S.	A.	S.	A.	L.	C.
	Thermometer highest at lowest station.	Thermometer lowest at lowest station.										
			40°	4·7689067	75°	4·7859208	110°	4·8022936	145°	4·8180714	0	0·0011689
			41	·7694021	76	·7863973	111	·8027525	146	·8185140	3	·0011624
			42	·7698971	77	·7868733	112	·8032109	147	·8189559	6	·0011433
0°	0·0000000	0·0000000	43	·7703911	78	·7873487	113	·8036687	148	·8193975	9	·0011117
1	·0000434	9·9999566	44	·7708851	79	·7878236	114	·8041261	149	·8198387	12	·0010679
2	·0000869	·9999131	45	·7713785	80	·7882979	115	·8045830	150	·8202794	15	·0010124
3	·0001303	·9998697	46	·7718711	81	·7887719	116	·8050395	151	·8207196	18	·0009459
4	·0001737	·9998262	47	·7723633	82	·7892451	117	·8054953	152	·8211594	21	·0008689
5	·0002171	·9997828	48	·7728548	83	·7897180	118	·8059509	153	·8215988	24	·0007825
6	·0002605	·9997393	49	·7733457	84	·7901903	119	·8064058	154	·8220377	27	·0006874
7	·0003039	·9996959	50	·7738363	85	·7906621	120	·8068604	155	·8224761	30	·0005848
8	·0003473	·9996524	51	·7743261	86	·7911335	121	·8073144	156	·8229141	33	·0004758
9	·0003907	·9996090	52	·7748153	87	·7916042	122	·8077680	157	·8233517	36	·0003615
10	·0004341	·9995655	53	·7753042	88	·7920745	123	·8082211	158	·8237888	39	·0002433
11	·0004775	·9995220	54	·7757925	89	·7925441	124	·8086737	159	·8242256	42	·0001223
12	·0005208	·9994785	55	·7762802	90	·7930135	125	·8091258	160	·8246618	45	·0000000
13	·0005642	·9994350	56	·7767674	91	·7934822	126	·8095776	161	·8250976	48	9·9998775
14	·0006076	·9993916	57	·7772540	92	·7939504	127	·8100287	162	·8255331	49	·9998372
15	·0006510	·9993481	58	·7777400	93	·7944182	128	·8104795	163	·8259680	50	·9997967
16	·0006943	·9993046	59	·7782256	94	·7948854	129	·8109298	164	·8264024	51	·9997566
17	·0007377	·9992611	60	·7787105	95	·7953521	130	·8113796	165	·8268365	52	·9997167
18	·0007810	·9992176	61	·7791949	96	·7958184	131	·8118290	166	·8272701	53	·9996772
19	·0008244	·9991741	62	·7796788	97	·7962841	132	·8122778	167	·8277034	54	·9996381
20	·0008677	·9991305	63	·7801622	98	·7967493	133	·8127263	168	·8281362	55	·9995995
21	·0009111	·9990870	64	·7806450	99	·7972141	134	·8131742	169	·8285685	56	·9995613
22	·0009544	·9990435	65	·7811272	100	·7976784	135	·8136216	170	·8290005	57	·9995237
23	·0009977	·9990000	66	·7816090	101	·7981421	136	·8140688	171	·8294319	58	·9994866
24	·0010411	·9989564	67	·7820902	102	·7986054	137	·8145153	172	·8298629	59	·9994502
25	·0010844	·9989129	68	·7825709	103	·7990681	138	·8149614	173	·8302937	60	·9994144
26	·0011277	·9988694	69	·7830511	104	·7995303	139	·8154070	174	·8307238	63	·9993115
27	·0011710	·9988258	70	·7835306	105	·7999921	140	·8158523	175	·8311536	66	·9992161
28	·0012143	·9987823	71	·7840098	106	·8004533	141	·8162970	176	·8315830	69	·9991293
29	·0012576	·9987387	72	·7844883	107	·8009142	142	·8167413	177	·8320119	75	·9989852
30	·0013009	·9986952	73	·7849664	108	·8013744	143	·8171852	178	·8324404	81	·9988854
31	·0013442	·9986516	74	·7854438	109	·8018343	144	·8176285	179	·8328686		

Make $R = \log. \beta - (B + \log. \beta.')$

The log. diff. of alt. in English feet $= A + C + \log.$ of R.

$\beta' =$ height of the barometer at the upper station.

$\beta =$ height of the barometer at the lower station.

$S =$ sum of the detached thermometers at the two stations.

$D =$ difference of the attached thermometers at the two stations.

$L =$ latitude of the place of observation.

The degrees of temperature according to Fahrenheit.

$A = \log. \{60345{\cdot}51 \times [1 + {\cdot}00111111\,(t + t' - 64^{\circ}]\}$

$B = \log. \{1 + {\cdot}0001\,(T - T')\}$

$C = \log. \{1 + {\cdot}002695 \cos. 2\,\phi\}$

$\phi =$ the latitude of the place of observation.

$$\left.\begin{array}{l} T = \text{the temperature of the mercury} \\ t = \text{the temperature of the air} \end{array}\right\} \text{at the lower station.}$$

$$\left.\begin{array}{l} T' = \text{the temperature of the mercury} \\ t' = \text{the temperature of the air} \end{array}\right\} \text{at the upper station.}$$

DIRECTIONS FOR USING THE FOREGOING TABLE.

To the log. of the height of barometer at the upper station, add the number from the proper column in B, opposite the difference of the degrees read on the attached thermometers at the two stations, and subtract their sum from the log. of the height of the barometer at the lower station, and call this result R; then to the log. of R add the number in A opposite the sum of the degrees read on the detached thermometers at the two stations, and also add the number in C, opposite the latitude of the place, and the sum, rejecting the tens from the index, will be the log. difference of altitude in feet.

Example I.

Station.	Barometer.	Attach. Ther.	Detach. Ther.
Lake	29·950	50°	49°
Mountain.....	27·474	44	45
Latitude 55° ..			

Log. of 27·474	1·4389219
B . . 50° — 44° = 6° .	0·0002605
	1·4391824
Log of 29·950	1·4763968
R	0·0372144
Log. of R.	8·5707110
A . . 49° + 45° = 94°	4·7948854
C . . . 55° . . .	9·9995995
Log. diff. of altitude . .	3·3651959 = 2318·44 feet.

Example II.

Station.	Barometer.	Attach. Ther.	Detach. Ther.
Wharf........	29·799	39°	37°·5
Hill..........	29·384	45	46 ·0
Latitude 51° 30′			

Log. of 29·384	1·4681109
B . . 45° — 39° = 6° .	9·9997393
	1·4678502
Log of 29·799	1·4742017
R	0·0063515
Log. of R	7·8028763
A 46° + 37°·5 = 83°·5 .	4·7899541
C 51° 30′	9·9997367
Log. diff. of altitude . .	2·5925671 = 391·35 feet.

Many years ago the celebrated Ramsden published a table for determining an approximation to heights by the mountain barometer, without the delay and trouble attending a logarithmic calculation, which was printed on a narrow slip of paper about a foot long. Upon comparing a result as given by this table, with one obtained by logarithms, there was found to be only a difference of 18 feet in a height of 3730 feet. At a later period, Messrs. Jones, formerly of Charing Cross, but now established at No. 4, Rupert Street, Leicester Square, published a set of tables, styled "A Companion to the Mountain Barometer," which were not only more elaborate, but included more data, than the simpler table of Ramsden; and therefore gave a much nearer approximation to the truth. In 1841, the Russian Government caused tables to be printed at St. Petersburg, which embrace an element not allowed for in those of Messrs. Jones, viz., the pressure of vapour upon the barometric column of mercury; and previously to reprinting their own tables, Messrs. Jones deemed it incumbent on them to make trial of the Russian tables; when they found it would be necessary to make an observation at every station with Masson's Hygrometer, which would be impracticable.

As the results to be obtained by using the tables of Messrs. Jones furnish so near an approximation to the truth; giving us indeed all that we have any right to look for from barometric measurements, we can recommend them to the notice of the public.*

The most approved mountain barometer is that of the eminent French philosopher, M. Gay Lussac; which consists of a small glass syphon tube, enclosed in a brass

* Our civil engineers have of late made great use of the mountain barometer when selecting lines for railways, and also for making rough sections to determine their practicability; but for accurate work there is no fear of the spirit level being ever superseded by the barometer.

one, of about 5-8ths of an inch diameter, which is graduated, and provided with two verniers, by means of which the length of the mercurial column may be read off at once to 500ths of an inch. A thermometer is attached, the bulb of which passes through the brass tube, and touches the glass one. The whole goes into a leathern case, little larger than a stout walking-cane; which, being lined with tin, affords an excellent protection to the instrument. A common gimlet accompanies the barometer, to serve as a hook upon which to suspend it when in use. The great superiority of this construction consists in the extreme portability of the instrument, which has only to be reversed —that is, turned over end—and kept in a nearly upright position; and it may be carried from place to place with perfect safety, moderate care being used.

Messrs. Troughton and Simms have improved upon the French construction, by placing the zero at the bottom of the scale, causing both verniers to read upwards, instead of having it in the middle, which occasions the readings to be contrary ways, and likely to be productive of error. Col. Mudge used this barometer extensively in his survey of the north-east boundary in America; and, as I am informed, pronounced very favourably with respect to its merits.

TO DETERMINE ALTITUDES BY THE DIFFERENT TEMPERATURES AT WHICH WATER BOILS.

If water be placed in a suitable vessel on a common fire, or over the flame of a lamp, it is gradually heated to a certain degree; and then small bubbles of aëriform matter (steam) are seen forming at the bottom of the vessel, and successively rising to the surface, where they disappear by mixing with the atmosphere; and, the operation being

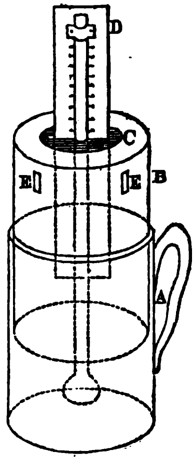
continued, the quantity of water diminishes with every bubble, until the whole disappears in the form of air.

Under common circumstances, this change in water takes place when it has attained the heat of 212° of the thermometer (Fahrenheit's). But a less degree of heat produces the same effect if the pressure of the atmosphere be lessened or removed; and a greater degree is required when the atmospheric pressure is increased. On the summit of Mont Blanc, water boils at 180°, owing to its being relieved from the pressure of a column of air equal to the height of the mountain; and at all intermediate heights, in descending to the level of the sea, there is a corresponding increase of the boiling temperature. Hence is derived a valuable method of ascertaining the heights of places, by simply observing the heat at which water boils.

A paper has recently been published, by that scientific officer, Colonel W. H. Sykes, of the Indian Army, on the method of determining heights by this means: and Mr. Prinsep having computed the necessary tables, the operation is thereby rendered exceedingly simple. The results obtained by using these tables give a rather less elevation than what we arrive at by careful barometrical observations. It is not, however, to be supposed that either the thermometer when immersed in boiling water, or the barometer when used with the table and formulæ, as given at page 255, and following ones, of this book, can ever furnish so exact a measurement as we obtain by levelling, or trigonometrically; still, as both methods afford a close approximation, they are of great value: and, with reference to that by boiling water, the necessary apparatus is very simple, and not liable to injury like the barometer, besides being more portable and easily replaced, should an accident occur.

The accompanying sketch and explanation, taken from

Colonel Sykes's pamphlet, show the whole apparatus required:—



A, a common tin pot, 9 inches high, by 2 in the diameter.

B, a sliding tube of tin, moving up and down in the pot; the head of the tube is closed, but has a slit in it, C, to admit of the thermometer passing through a collar of cork, which shuts up the slit where the thermometer is placed.

D, thermometer, with so much of the scale left out as may be desirable.

E, holes for the escape of steam.

The pot is filled four or five inches with *pure* water; the thermometer fitted into the aperture in the lid of the sliding tube, by means of a collar of cork; and the tin sliding tube pushed up or down to admit of the bulb of the thermometer being about two inches from the bottom of the pot.

Before using a thermometer for this purpose, it is necessary to ascertain if the boiling point is correctly marked for the level of the sea by a number of careful observations, and the difference, if any, must be noted as an *index error*. It is always desirable to have two or more thermometers which have been thus tested; and in all observations the temperature of the air at the time should be noted.

A few minutes will suffice for the whole operation; and where *very great accuracy* is not required, this method is certainly preferable to the barometer for determining altitudes, on account of the portability and cheapness of the apparatus,* and its not being, like the other more costly and accurate instrument, constantly liable to injury.

* This can be procured, ready for use, at Newman's, optician, Regent-street.

TABLE I.

TO FIND THE BAROMETRIC PRESSURE AND ELEVATION CORRESPONDING TO ANY OBSERVED TEMPERATURE OF BOILING WATER BETWEEN 214° AND 180°.

[*The Fourth Column gives the Heights in Feet*].

Boiling Point of Water.	Barometer Modified from Tredgold's Formula.	Logarithmic Differences or Fathoms.	Total Altitude, from 30·00 in., or the Level of the Sea.	Value of each Degree in Feet of Altitude.	Proportional Part for One-tenth of a Degree.
Degrees.			Feet.	Feet.	Feet.
214	31·19	60·84·3	−1013	−505	..
213	30·59	84·5	507	−507	..
212	30·00	84·9	0	+509	..
211	29·42	85·2	+ 509	511	51
210	28·85	85·5	1021	513	..
209	28·29	85·8	1534	515	..
208	27·73	86·2	2049	517	..
207	27·18	86·6	2566	519	52
206	26·64	87·1	3085	522	..
205	26·11	87·5	3607	524	..
204	25·59	87·8	4131	526	..
203	25·08	88·1	4657	528	..
202	24·58	88·5	5185	531	53
201	24·08	88·9	5716	533	..
200	23·59	89·3	6250	536	..
199	23·11	89·7	6786	538	..
198	22·64	90·1	7324	541	54
197	22·17	90·5	7864	543	..
196	21·71	91·0	8407	546	..
195	21·26	91·4	8953	548	..
194	20·82	91·8	9502	551	55
193	20·39	92·2	10053	553	..
192	19·96	92·6	10606	556	..
191	19·54	93·0	11161	558	..
190	19·13	93·4	11719	560	56
189	18·72	93·8	12280	563	..
188	18·32	94·2	12843	565	..
187	17·93	94·8	13408	569	57
186	17·54	95·3	13977	572	..
185	17·16	95·9	14548	575	58
184	16·79	96·4	15124	578	..
183	16·42	96·9	15702	581	..
182	16·06	97·4	16284	584	..
181	15·70	97·9	16868	587	..
180	15·35		17455		59

TABLE II.

TABLE OF MULTIPLIERS TO CORRECT THE APPROXIMATE HEIGHT FOR THE TEMPERATURE OF THE AIR.

Temperature of the Air.	Multiplier.	Temperature of the Air.	Multiplier.	Temperature of the Air.	Multiplier.
°		°		°	
32	1·000	52	1·042	72	1·083
33	1·002	53	1·044	73	1·085
34	1·004	54	1·046	74	1·087
35	1·006	55	1·048	75	1·089
36	1·008	56	1·050	76	1·091
37	1·010	57	1·052	77	1·094
38	1·012	58	1·054	78	1·096
39	1·015	59	1·056	79	1·098
40	1·017	60	1·058	80	1·100
41	1·019	61	1·060	81	1·102
42	1·021	62	1·062	82	1·104
43	1·023	63	1·064	83	1·106
44	1·025	64	1·066	84	1·108
45	1·027	65	1·069	85	1·110
46	1·029	66	1·071	86	1·112
47	1·031	67	1·073	87	1·114
48	1·033	68	1·075	88	1·116
49	1·035	69	1·077	89	1·118
50	1·037	70	1·079	90	1·121
51	1·039	71	1·081	91	1·123

When the thermometer has been boiled at the foot and at a summit of a mountain, nothing more is necessary than to deduct the number in the column of feet opposite the boiling point below, from the same of the boiling point above: this gives an approximate height, to be multipled by the number opposite the *mean* temperature of the air in Table II., for the correct altitude.

	°	feet.
Boiling point at summit of Hill Fort of Púrundhur, near Púna . .	204·2 =	4027
Boiling point at Hay Cottage, Púna .	208·7 =	1690
Approximate height .		2337
Temperature of the air above	75°	
Ditto ditto below	83	
Mean . .	79 = Multiplier	1·098
Correct altitude .		2566 ft.

When the boiling point at the upper station alone is observed, and for the lower the level of the sea or the register of a distinct barometer is taken, then the barometric reading had better be converted into feet, by the usual method of subtracting its logarithm from 1·47712 (log. of 30 inches) and multiplying by ·0006, as the differences in the column of "*barometer*" vary more rapidly than those in the "*feet*" column.

	feet.
Example.—Boiling point at upper station 185° =	14548
Barometer at Calcutta (at 32°) 29 in. 75	
Log. diff. = 1·47712 − 1·47349 = 00363 × 0006 =	218
Approximate height .	14330
Temperature, upper station, 76° / Ditto lower, 84 } 80 = multiplier	1·100
Correct altitude . .	15763

Assuming 30·00 inches as the average height of the barometer at the level of the sea (which is, however, too much), the altitude of the upper station is at once obtained by inspection of Table I., correcting for temperature of the stratum of air traversed by Table II.

SECTION XX.

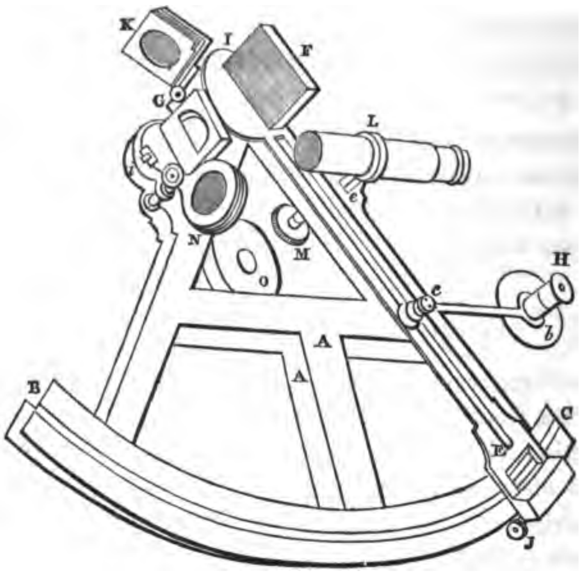
DESCRIPTION AND USE OF THE SEXTANT — ITS ADJUSTMENTS—ARTIFICIAL HORIZON—METHOD OF USING IT — PARALLAX — REFRACTION — TO FIND THE VARIATION OF THE NEEDLE.

DESCRIPTION AND USE OF THE SEXTANT.

THE large sextant differs, both in form and in its adjustments, from the pocket box-sextant, which is described in Section XIII.; it is used for measuring the altitudes of, and distances between, heavenly bodies. The following description of the sextant is principally taken from Mr. F. Simms's work on Instruments.

The annexed figure represents a sextant of Troughton's construction, having a double frame, A A, connected by pillars, thus uniting strength with lightness. The arc, B C, is generally graduated to 10 minutes of a degree, commencing near the end, C, and it is numbered towards B. The divisions are also continued on the other side of zero, towards C, forming what is called the arc of excess, which is useful in determining the index-error of the instrument, as will be explained hereafter. The limb is subdivided by the vernier, E, into 10″, the half of which (or 5″) can be easily estimated: this small quantity is easily distinguishable by the aid of the microscope, H, and its reflector, *b*, which are connected by an arm with the index, I E, at the point *c*, round which it turns as a centre, affording the

means of examining the whole vernier, the connecting arm being long enough to allow the microscope to pass over the whole of it.



To the index is attached a clamp to fasten it to the limb, and a tangent-screw, J (in the figure the clamp is concealed from view), by which the index may be moved any small quantity, after it is clamped, to render the contact of the objects observed more perfect than can be done by moving it with the hand alone. The upper end, I, terminates in a circle, across which is fixed the silvered index-glass, F, over the centre of motion, and perpendicular to the plane of the instrument. To the frame at G is attached a second glass, called the horizon-glass, the lower half of which only is silvered: this must likewise be perpendicular to the plane of the instrument, and in such a position that its plane shall be parallel to the plane of the index-glass, F, when

the vernier is set to 0° (or zero) on the limb, B C. A deviation from this position constitutes the index-error, before spoken of.

The telescope is carried by a ring, L, attached to a stem, *e*, called the up-and-down piece, which can be raised or lowered, by turning the milled-screw, M: its use is to place the telescope so that the field of view may be bisected by the line on the horizon-glass that separates the silvered from the unsilvered part. This is important, as it renders the object seen by reflection, and that by direct vision, equally bright:* two telescopes, and a plain tube, all adapted to the ring, L, are packed with the sextant, one showing the objects erect, and the other inverting them; the last has a greater magnifying power, showing the contact of the images much better. The adjustment for distinct vision is obtained by sliding the tube at the eye-end of the telescope in the inside of the other: this also is the means of adapting the focus to suit different eyes. In the inverting telescope are placed two wires, parallel to each other, and in the middle of the space between them the observations are to be made, the wires being first brought parallel to the plane of the sextant, which may be judged of with sufficient exactness by the eye. When observing with the telescope, it must be borne in mind, that the instrument is to be moved in a contrary direction to that which the object appears to take, in order to keep it in the field of view.

Four dark glasses, of different depths of shade and colour, are placed at K, between the index and horizon glasses;

* This is not the case when one object is much brighter than the other, as the sun and moon; in taking the distance between which, the screw, M, should be moved more than above stated, until they are both nearly of the same brightness, as an observation can be made better when this is the case, than when otherwise.

also three more at N, any one or more of which can be turned down to moderate the intensity of the light, before reaching the eye, when a very luminous object (as the sun) is observed. The same purpose is effected by fixing a dark glass to the eye-end of the telescope: one or more dark glasses for this purpose generally accompany the instrument. They, however, are chiefly used when the sun's altitude is observed with an artificial horizon, or for ascertaining the index-error; as employing the shades attached to the instrument for such purposes would involve in the result any error which they might possess. The handle, which is shown at O, is fixed at the back of the instrument. The hole in the middle is for fixing it to a stand, which is useful when an observer is desirous of great steadiness.

OF THE ADJUSTMENTS.

The requisite adjustments are the following:—The index and horizon glasses must be perpendicular to the plane of the instrument, and their planes parallel to each other, when the index division of the vernier is at 0° on the arc; and the optical axis of the telescope must be parallel to the plane of the instrument. We shall speak separately of each of these adjustments.

TO EXAMINE THE ADJUSTMENT OF THE INDEX-GLASS.

Move the index forward to about the middle of the limb, then, holding the instrument horizontally with the divided limb towards the observer, and the index-glass to the eye, look obliquely down the glass, so as to see the circular arc, by direct view and by reflection, in the glass at the same time; and if they appear as one continued circle, the index-glass is in adjustment. If it requires correcting,

the arc will appear broken where the reflected and direct parts of the limb meet. This, in a well-made instrument, is seldom the case unless the sextant has been exposed to rough treatment; as the glass is, in the first instance, set right by the maker and firmly fixed in its place, and, its position not being liable to alter, no direct means are supplied for its adjustment.

TO EXAMINE THE HORIZON-GLASS AND SET IT PERPENDICULAR TO THE PLANE OF THE SEXTANT.

The position of this glass is known to be right when, by a sweep with the index, the reflected image of any object passes exactly over or covers its image as seen directly; and any error is easily rectified by turning the small screw, *i*, at the lower end of the frame of the glass.

TO EXAMINE THE PARALLELISM OF THE PLANES OF THE TWO GLASSES, WHEN THE INDEX IS SET TO ZERO.

This is easily ascertained; for, after setting the zero on the index to the zero on the limb, if you direct your view to some object, the sun for instance, you will see that the two images (one seen by direct vision through the unsilvered part of the horizon-glass, and the other reflected from the silvered part) coincide or appear as one, if the glasses are correctly parallel to each other; but, if the two images do not coincide, the quantity of their deviation constitutes what is called the index-error. The effect of this error on an angle measured by the instrument is exactly equal to the error itself; therefore, in modern instruments, there are seldom any means applied for its correction, it being considered preferable to determine its amount previous to observing, or immediately after, and apply it with its

proper sign to each observation. The amount of the index-error may be found in the following manner:—Clamp the index at about 30′ to the left of zero, and, looking towards the sun, the two images will appear either nearly in contact or overlapping each other; then perfect the contact, by moving the tangent-screw, and call the minutes and seconds denoted by the vernier, the reading *on the arc*. Next place the index about the same quantity to the right of zero, or on the arc of excess, and make the contact of the two images perfect as before, and call the minutes and seconds on the arc of excess,* the reading *off the arc*, and half the difference of these numbers is the index-error: additive when the reading on the arc of excess is greater than that on the limb, and subtractive when the contrary is the case.

EXAMPLE.

Reading on the arc	31′	56″
Reading off the arc	31	22
Difference . . .	0	34
Index-error . . .	0	17

In this case, the reading on the arc being greater than that on the arc of excess, the index-error, = 17″, must be subtracted from all observations taken with the instrument, until it be found, by a similar process, that the index-error has altered. One observation on each side of zero is seldom considered enough to give the index-error with sufficient exactness for particular purposes; it is usual to take several measures each way, and half the difference of their means will give a result more to be depended on than

* When reading off the arc of excess, the vernier must be read backwards, or from its contrary end.

one deduced from a single observation only on each side of zero. A proof of the correctness of observations for index-error is obtained by adding the above numbers together and taking one-fourth of their sum, which should be equal to the sun's semidiameter as given in the "Nautical Almanac." When the sun's altitude is low, not exceeding 20° or 30°, his horizontal, instead of his perpendicular, diameter should be measured (if the observer intends to compare with the "Nautical Almanac," otherwise there is no necessity); because the refraction at such an altitude affects the lower part (or limb) more than the upper, so as to make his perpendicular diameter appear less than his horizontal one, which is that given in the "Nautical Almanac:" in this case the sextant must be held horizontally.

TO MAKE THE LINE OF COLLIMATION OF THE TELESCOPE PARALLEL TO THE PLANE OF THE SEXTANT.

This is known to be correct when the sun and moon, having a distance of 90° or more, are brought into contact just at the wire of the telescope which is nearest the plane of the sextant, fixing the index and altering the position of the instrument, to make the objects appear on the other wire; if the contact still remains perfect, the telescope is in proper adjustment; if not, it must be altered by moving the two screws which fasten to the up-and-down piece the collar into which the telescope screws. This adjustment is not very liable to be deranged.

Having now gone through the construction and adjustments of the sextant, it remains to give some instructions as to the manner of using it. For the principle of the sextant see page 96.

It is evident that the plane of the instrument must be held in the plane of the two objects, the angular distance of which is required: in a vertical plane, therefore, when altitudes are measured; in a horizontal or oblique plane, when horizontal or oblique angles are to be taken. As this adjustment of the plane of the instrument is rather difficult and troublesome to the beginner, he need not be surprised nor discouraged, although his first attempts may not answer his expectations. The sextant must be held in the right hand, and as slack as is consistent with its safety, for in grasping it too hard, the hand is apt to be rendered unsteady.

When the altitude of an object, the sun for instance, is to be observed, the observer, having the sea-horizon before him, must turn down one or more of the dark glasses or shades, according to the brilliancy of the object; and directing his sight to that part of the horizon immediately beneath the sun, and holding the instrument vertically, he must with the left hand lightly slide the index forward until the image of the sun, reflected from the index-glass, appears in contact with the horizon, seen through the unsilvered part of the horizon-glass. Then clamp it firm and gently turn the tangent-screw, to make the contact of the upper or lower limb of the sun and the horizon perfect, when it will appear a tangent to his circular disc.* If an artificial horizon is employed, the two images of the sun must be brought into contact with each other, the index-

* If the observer knows his latitude approximately, he may find the meridional altitude nearly, to which he may previously set his instrument; when he will not only find his object more easily, but have only a small quantity to move the index to perfect the observation.

Take from the "Nautical Almanac" the declination of the object, and, if it be the same name with the latitude, add it to the co-latitude: if of a different name, subtract it: the sum or difference will be the meridian altitude.

error is applied to the angle read off; half of this has then to be corrected, as will be seen under the head of Artificial Horizon. When the sea-horizon is employed, a quantity must also be subtracted for the dip, occasioned by the height of the eye above the level of the sea, as in a ship; which is not required when the altitude is taken by means of an artificial horizon. Tables for all these corrections may be found in any modern work upon navigation.

If the observer is ignorant of the precise moment of the object's being on the meridian, he should, by a slow and gradual motion of the tangent-screw, keep the observed limb in contact with the horizon as long as it continues to rise; and immediately on the altitude appearing to diminish, cease from observing; and the angle then read on the instrument will be the meridian altitude.

After what has been advanced little need be said about observing lunar distances, whether of the moon and the sun, or the moon and a fixed star or planet, except that the instrument must be held in the plane of the two objects; and it is generally preferable to direct the telescope to the fainter object, particularly if a star, as it can be more easily kept in view when seen directly than it can when seen by reflection. If the brighter object is to the left, the sextant must be held with the face downwards.

The enlightened limb of the moon is always to be brought into contact with the sun or star, even though the moon's image is made to pass beyond the sun or star before the desired contact can be obtained.

Perhaps the best method of taking a lunar distance is, not to attempt to make the contact perfect by the tangent-screw, but, when the nearest limbs are observed, make the objects overlap each other a little when they are receding,

or leave a small space between them when they are approaching; and wait till the contact is perfect, and the reverse when the furthest limbs are observed.

Of the sextant it has been said, that it is in itself a portable observatory; and it is doubtless one of the most generally useful instruments that has ever been contrived, being capable of furnishing data, to a considerable degree of accuracy, for the solution of a numerous class of the most useful astronomical problems, affording the means of determining the time, the latitude and longitude of a place, &c., for which, and many other purposes, it is invaluable to the traveller, the maritime surveyor, and the navigator.

ARTIFICIAL HORIZON: METHOD OF USING IT.

When the altitude of a celestial object is to be taken at sea, the observer has the natural (or sea) horizon, as a line of departure; but on shore he is obliged to have recourse to an artificial one, to which his observations may be referred: this consists of a reflecting plane, parallel to the natural horizon, on which the rays of the sun, or other object, falling, are reflected back to the eye, placed in a proper position to receive them: the angle between the real object and its reflected image, being then measured with the sextant, is *double* the altitude of the object above the horizontal plane.

Such an horizontal plane may be obtained by pouring a quantity of oil, tar, treacle, or other fluid and viscous substance, into a shallow vessel; and, to prevent the wind giving a tremulous motion to its surface, a piece of thin gauze, muslin, or plate-glass, whose surfaces are perfectly

plane and parallel, may be placed over it when used for observation.

For portability, an artificial horizon sometimes consists of a plane speculum, or plate of glass, from two to three inches in diameter, fixed in a brass frame standing upon three adjusting screws, by which its surface may be made perfectly horizontal, with the assistance of a small spirit-level, placed on its surface in various positions; observing that the screws be turned, until the air-bubble always rests in the middle of the tube. The under surface of the plate-glass is sometimes unpolished and blackened, so that the image of the sun can only be reflected from the upper surface, which should be carefully polished, and a perfect plane; by this means the errors that might arise from a defect of parallelism in the two surfaces are avoided.

But the best kind of artificial horizon is that produced by quicksilver, which, being poured into a shallow wooden trough, will always, agreeably to the nature of fluids, preserve an exact horizontal plane at its surface; over this is placed a roof, to protect the quicksilver from the action of the wind, in which are fixed two plates of glass, the surfaces of each being ground perfectly flat and parallel to each other. These are usually packed in a small mahogany box, with a vessel containing a quantity of quicksilver ready for use when wanted.

When an artificial horizon is used, the observer must place himself at such a distance that he may see the object himself, and also its reflected image: then, supposing he is taking an altitude of the sun, the upper or lower limb of its image, reflected from the index-glass, must be brought into contact with the opposite limb of the image reflected from the artificial horizon, observing that, when the inverting telescope with which large sextants are furnished,

is used, the upper limb will appear as the lower, and *vice versa*;* the angle shown on the instrument will be double the altitude of the sun's limb above the horizontal plane;† to the half of which, if the corrections for semidiameter, refraction, and parallax be applied, the result will be the true altitude of the sun's centre.

EXAMPLE.

Observed angle	99°	45′	0″
Apparent altitude	49	52	30
Semidiameter	+	15	49
Parallax	+	0	6
	50	8	25
Refraction (always deducted) . .	—	0	48
True altitude of sun's centre . .	50	7	37

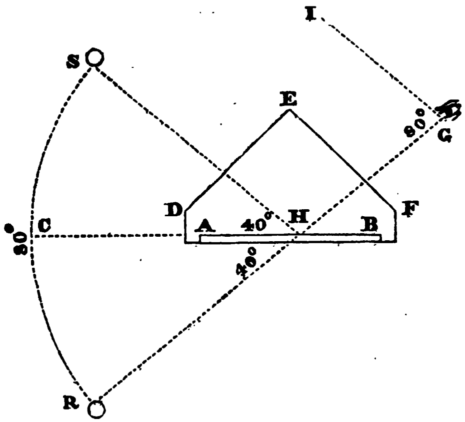
The diagram in next page will illustrate the method of observing altitudes with an artificial horizon:—

Let A B represent the surface of the quicksilver contained in a wooden trough, whose plane is continued to C; D E F the roof, in which are fixed two plates of glass, D E and E F, whose surfaces are plane and parallel to each

* When the contact is formed at the lower limb, the images will separate shortly after the contact has been made, if the altitude be increasing; but, if the altitude be decreasing, they will begin to overlap; when, however, the contact is formed at the upper limb, the reverse takes place. An observer, if in doubt as to which limb he has been observing, should watch the object for a short time after he has made the observation.

† When observing with a large sextant, there is commonly what is termed the index-error to be added or subtracted; this error arises from the glasses of the instrument not being perfectly parallel; and the quantity of their deviation measured on the arc constitutes the index-error, which is usually allowed for, in preference to adjusting the glasses to exact parallelism.

other: and ☉ the sun at S, whose altitude is required. Now the ray, S H, proceeding from the sun's lower limb to the surface of the quicksilver, will be reflected thence to the eye in the direction, H G, and the upper limb of the



sun's image, reflected from the quicksilver, will appear in the line, G H, continued to R; and it is a well-known principle in catoptrics, that the angle of incidence, S H A or S H C, is equal to the angle of reflection, G H B; and as the angle, A H R or C H R, is the opposite angle of G H B, it is, therefore, equal to it, and to the angle, S H C, the altitude of the sun's lower limb above the horizontal plane; so that, if we suppose the angle, S H R, measured by a sextant, to be 80°, the altitude of the sun's lower limb will be 40°, subject to the corrections, as above.

In the example given of observing an altitude of the sun, its semidiameter is added. The apparent diameter of the sun, moon, &c., is the angle under which they appear to an observer situated on the earth; the amount of which depends upon the real magnitude of the object, and its distance from the observer. The sun's semidiameter is set

down in the "Nautical Almanac," "White's Ephemeris," &c. Its mean semidiameter is 16′, which is the quantity used in common practice, as it never varies more than half a minute from that amount.

PARALLAX.

The situation of a celestial body, when viewed from the surface of the earth, is called its *apparent* place, and that part of the heavens where it would be seen, if observed at the same time from the *centre* of the earth, is called its *true* place. The difference between the true and apparent places is termed the parallax of the object. The parallax of an object is greatest at the horizon, and gradually diminishes as the body rises above the horizon, until it comes to the zenith, where the parallax vanishes. It is evident that the altitude of an object seen from the earth's surface is less than it would be if seen from the centre; hence the parallax is to be added to the apparent altitude, in order to obtain the true altitude. The sun's mean horizontal parallax is $8\frac{3}{4}''$.

REFRACTION.

The third correction for an altitude of the sun is on account of refraction. The rays of light which proceed from a celestial body, on entering the atmosphere in an oblique direction, are bent out of their rectilinear course, and incline more and more towards the centre of the earth as they pass deeper into the atmosphere, and hence enter the eye of an observer in a different direction from that of the object, and make it appear higher than its real place. And the difference between the real and apparent places of the heavenly bodies, as affected by the passage of the rays of light through the atmosphere, is called the *refraction*

of the object. The more obliquely the rays enter the atmosphere, the more they will be bent out of their rectilinear course, and hence the greater the refraction : consequently, refraction is greatest at the horizon, and ceases at the zenith. Refraction is always to be subtracted from the apparent altitude of an object, because the effect of refraction is to cause bodies to appear higher than they really are; so much so that the sun, stars, &c., may actually be below the horizon, when they appear above it. In nautical and astronomical works, tables of refraction are usually given. For terrestrial refraction, see *Levelling*.

TO FIND THE VARIATION OF THE NEEDLE.

The following method of finding the variation is sufficiently exact for ordinary purposes, but not accurate enough for fixing a true meridian, owing to the uncertainty of the refraction; but, if the sun ascends or descends with little obliquity, the error will not then be very considerable.

When the sun's lower edge or limb is a semidiameter above the horizon (at which time its centre is really about on the horizon, although it is apparently elevated, on account of the refraction of the atmosphere), take the bearing of its centre from the N. or S., whichever it is nearest, with an azimuth compass. The prismatic surveying compass will do, if provided with what is termed an azimuth. The thread is made to bisect the sun's disc, and the observed bearing subtracted from 90° will be the sun's magnetic amplitude, or distance from the E. or W. points by the needle.

Next calculate the sun's true amplitude for that day, thus:—

To the log. secant of the latitude, rejecting the index, add the log. sine of the sun's declination, corrected for the

time and place of observation, from a table for that purpose; their sum will be the log. sine of the true amplitude. Or by another rule :—

As the cosine of the latitude is to the radius, so is the sine of the sun's declination at setting or rising to the sine of its amplitude from the W. or E. To be reckoned from the east in the morning, or the west in the afternoon, and it will be N. or S., as the sun's declination is N. or S.; and the distance in degrees and minutes between the true E. or W. and the magnetic is the variation of the needle.

Observe, if the true and magnetic amplitudes be both north or both south, their difference is the variation; but if one be north and the other south, their sum is the variation: and, to know whether it be easterly or westerly, suppose the observer looking towards that point of the compass representing the magnetic amplitude; then, if the true amplitude be to the right hand of the magnetic, the variation is east, but if to the left hand, it is west.

Example I.

Required the sun's true amplitude on November 6th, 1828, *in latitude* 48° 21′.

Latitude . .	48°	21′ . .	Secant	0·17745
Declination .	16	4 S. .	Sine .	9·44210
True amplitude	24	37 . .	Sine .	9·61955

Hence the sun rose 24° 37′ south of E., and set 24° 37 south of W.

Example II.

July 3rd, 1828, *in latitude* 9° 36′ *S., the sun was observed to rise* 12° 42′ *north of E.: required the variation of the needle.*

Latitude . .	9°	36′ S. . .	Secant	0·00613
Declination .	22	58 N. . .	Sine .	9·59128
True amplitude	23	19 N. of E. .	Sine ,	9·59741
Mag. amplitude	12	42 N. of E.		

Variation . 10 37 W., because the true amplitude is to the left of the magnetic.

EXAMPLE III.

September 24th, 1828, in latitude 26° 32′ N., and longitude 43° W., the sun's centre was observed to set 6° 15′ S. of W. about 6 p. m.: required the variation of the needle.

Sun's declination .	0°	33′ S.		
Corr. for longitude	+	3		
Corr. for time 6 *p. m.*	+	6		
Reduced declination	0	42 S. . .	Sine .	0·08696
Latitude . . .	26	32 . .	Secant	0·04834
True amplitude .	0	47 S. of W.	Sine .	0·13530
Mag. amplitude .	6	15 S. of W.		

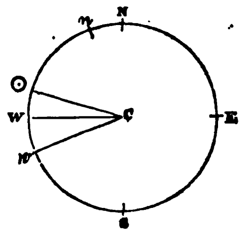
Variation . . . 5 28 E., because the true amplitude is to the right of the magnetic.*

An excellent way of preventing mistakes, which inexperienced observers are subject to, is to draw a rough diagram, thus: first, a circle to represent the visible boundary of the horizon, and on it to draw such lines as are necessary to render the figure complete; then it will at

* The necessary tables for the declination and corrections are given in the "Nautical Almanac," and in most works on navigation; some of them are also contained in "White's Ephemeris." This latter, with the addition of a few more tables, would be very useful to military men, and travellers generally, being so portable.

once appear how the variation is to be found, whether by addition or subtraction, and on which side of the north it lies. For example:—

We will suppose the variation to be sought at sun-setting. Draw a circle, N. W. S. E., to represent the visible horizon; in the middle of it mark the point, C, for your station; from C draw the line, C W, to represent the true west; then on the north or south side of that line, according as the sun sets north or south of the true west, draw the line, C ⊙, representing the direction of the sun's centre at setting; and another line, C *w*, for the magnetic west, either on the north or south side of ⊙, as it was observed to be, and at its judged distance. Then, by observing the situation of these lines, it will easily be seen whether the magnetic amplitude and true amplitude are to be added or subtracted to give the variation; and on which side of the true north the variation lies. In the present supposition *w* ⊙ is the magnetic amplitude, and ⊙ W the true amplitude: ⊙ W, therefore, must be subtracted from ⊙ *w*, to give *w* W, the distance of one from the other; and *n*, the magnetic N, 90° from *w*, must be westward of N, the true north.



SECTION XXI.

LATITUDE AND LONGITUDE.

War is the great pioneer of geography. Travellers, incited by motives of curiosity or science, may traverse distant lands, and impart to us much useful information respecting their natural phenomena, productions, and inhabitants; but, till countries have been actually surveyed for military purposes, they must remain but imperfectly known. All history bears witness to the truth of this observation, from the period of Alexander's conquests up to the time of our recent expedition into the Chinese empire.

There is no doubt that, with reference to most parts of the globe, lines of coast generally, together with remarkable points situated thereon, are traced upon maps and charts with tolerable accuracy, owing to the professional exertions of our naval brethren; but, beyond the confines of Europe, we have reason to believe that the courses of some of the greatest rivers, as well as the positions of many cities and towns, have been laid down on very loose authority.

Now, it must be admitted that officers, both of the Royal Army and East India Company's service, have greater opportunities than most persons of observing and correcting the errors of maps, and otherwise contributing to scientific knowledge, whether their wanderings into remote regions are occasioned by the calls of professional duty, or proceed from that spirit of enterprise so prevalent amongst them, which impels many to travel: and, in order that they may be able to avail themselves fully of such opportunities, it

is highly desirable that they should make themselves acquainted with the ordinary methods of determining latitude and longitude.

The latitude of a place may be obtained by the simplest of all astronomical observations, namely, that of taking a meridian altitude of the sun with a sextant; then, with a few necessary corrections, and the sun's declination being given, the latitude is found by a mere addition or subtraction, as the case may require.

As regards the longitude, the method most generally practised of obtaining it is by what is called a lunar observation; which is simply to measure very accurately the distance between the sun and moon, or between the moon and a star, when those objects are above the horizon, and within distance; that is, within the limits that a sextant will measure, namely to 120 degrees.* The altitudes of the sun and moon are to be taken at the same instant, and the apparent time at the moment of observation is to be noted by means of a watch, whose error has been previously ascertained by an observation. With these data, and a rule for the necessary calculation, aided by certain tables, any person acquainted with arithmetic and logarithms may work out the longitude; thus dispensing with all knowledge of geometry, trigonometry, or astronomy, and of course of any acquaintance with the principle upon which the calculation proceeds. In this way I have seen commanders, and mates of transports and merchant-vessels, men possessed of little more than such practical education as is to be acquired on board ship, bring out the longitude to within ten or twelve miles.

* Observations, both for the latitude and longitude, are as easily made by means of a star, as by the sun. For an *altitude* of the sun, or that of a star, a pocket-sextant may suffice; but in taking a *lunar*, as the accuracy of result depends upon the exactness with which the distance between the sun and moon, or the latter and a star, is measured, a larger sextant is necessary.

Here we have an instance of the vast importance of science to the concerns of life. The astronomer, acquainted with the moon's rate of motion, has deduced from it a method of finding what o'clock it is at two places situated under different meridians at the same instant of time; while the mathematician furnishes us with formulæ and tables, by means of which an intelligent shipboy is soon taught how to ascertain his vessel's longitude as well as it could be found by the man of science himself.

OF FINDING THE LATITUDE.

The latitude of a place is its distance from the equator, either north or south, and is measured by an arc of a meridian contained between the zenith and the equinoctial; hence, if the distance of any heavenly body from the zenith when on the meridian, and its declination, or number of degrees and minutes it is to the northward or southward of the equinoctial, be given, the latitude may then be obtained.

The meridian zenith distance of an object is found either from its altitude taken when on the meridian, or from one or two altitudes observed when out of the meridian.

Altitudes of the sun and moon taken on land require in strictness three corrections, in order to obtain the true altitude of their centres, to which all astronomical calculations respecting the heavenly bodies are adapted; these are for semidiameter, refraction, and parallax.* (See page 278, and following.) In taking an altitude of the sun, by means of a sextant and an artificial horizon (page 275), either the upper or lower limb may be used: if the former be taken, and the contact formed as noticed at page 275, it is evident that a quantity equal to the semidiameter of the sun must

* Parallax, being only a few seconds, is usually omitted in observations of this kind.

be added to the observed altitude, to give the altitude of his centre; but, if the altitude of the upper limb be taken, the semidiameter of the sun must be subtracted.

To find the latitude of a place by a meridian altitude of the sun.

Rule. To the observed altitude of the sun's lower limb add the sun's semidiameter (16 minutes);* but, if the upper limb be observed, subtract it, and the sum or remainder will be the apparent altitude of the sun's centre.

From the apparent altitude of the sun's centre subtract the refraction answering to that altitude, and the remainder will be the true altitude of the sun's centre.

Subtract the true altitude of the sun's centre from 90°, and the remainder will be the sun's true meridian zenith distance, which is to be called north or south according as the observer is north or south of the sun at the time of observation.

Take the sun's declination, and reduce it to the meridian of the place (when the longitude is considerable), noting whether it be north or south. Then, if the zenith distance and declination be both north or both south, add them together; but, if one be north and the other south, subtract the less from the greater, and the sum or difference will be the latitude, of the same name with the greater.†

EXAMPLE I.

June 18th, 1828, the meridian altitude of the sun's lower limb was 43° 18′, the observer being north of the sun; required the latitude of the place of observation.

* The semidiameter of 16′ is taken as a mean: it depends on the distance of the sun from the earth.

† The "Nautical Almanac," some books on navigation, "White's Ephemeris," and others, contain the tables of refraction, parallax, declination, correction for longitude, &c.

Obs. alt. sun's lower limb	43°	18′
Sun's semidiameter	+	16
Apparent alt. sun's centre	43	34
Refraction	—	1
True alt. sun's centre	43	33
	90	0
Sun's zenith distance	46	27 N.
Sun's declination	22	26 N.
Latitude	69	53 N.

Example II.

September 21st, 1829, in longitude 60° E., the meridian altitude of the sun's lower limb was 56° 26′, the observer being north of the sun; required the latitude of the place.

Obs. alt. sun's lower limb	56°	26′
Semidiameter	+	16
Apparent alt. sun's centre	56	42
Refraction	—	1
True alt. sun's centre	56	41
	90	0
Sun's zenith distance	33	19 S
Sun's declination . . . . . . 0° 44′ / Corr. for longitude . . . . . + 4	0	48 N.
Latitude	32	31 S.

OF FINDING THE LONGITUDE.

A variety of methods have been proposed for determining the longitude of a place, but almost all of them depend upon one general principle—namely, the comparison of the relative times under two different meridians; so that, if the time under a given meridian be known, and also the time under any other meridian, the difference of these times turned into degrees and minutes, in the proportion of 15 degrees to 1 hour, will be the difference of longitude between the two meridians. For as the sun *apparently* moves round the earth, from east to west, in 24 hours, or over an arc of 15 degrees of the equator in one hour of time, all places lying to the eastward of any meridian will have noon sooner—or, if to the westward, later—by as much time as the sun takes to pass from the meridian of one place to the meridian of the other: hence, if the time at the meridian of Greenwich (from whence the longitude is reckoned), and of any other place, at the same moment of absolute time, be given, its longitude from Greenwich may be inferred by reducing the difference of times into degrees and minutes, in the proportion of 15 degrees of longitude to 1 hour of time: moreover, if the time at the place be greater than that at Greenwich, its longitude will be east; but if less, it will be west. Thus, suppose it is ascertained that the time at Greenwich is 2 hours past noon, when it is just noon at any place; it will thence appear that the longitude of the place is 30 degrees west of the meridian of Greenwich, because the sun passes over 30 degrees of the equator in 2 hours of time; and, having left the meridian of Greenwich 2 hours since, such place must consequently be to the westward of that

meridian. If we suppose the time at the place to be 4 hours past noon, its longitude would be 30 degrees east of Greenwich, for the sun, in this case, would have passed its meridian 2 hours before it passed that of Greenwich.

Now, the time at any given meridian may be easily computed by an altitude of the sun or a star, taken when distant from the meridian, or from observations of the sun when at equal altitudes; and the time at Greenwich may be ascertained by means of a timekeeper, or by various astronomical observations. With respect to the first of these, it is obvious that, if a clock or watch could be so constructed as to go uniformly in all seasons and at all places, such a machine being once set to the time at Greenwich would always show the real time at Greenwich, in whatever part of the earth it might be; and, therefore, when the time under any other meridian was found, and compared with that shown by the timekeeper, the longitude of the place from Greenwich would be readily obtained. To effect this purpose several ingenious artists have exerted their abilities, and have brought timekeepers to an astonishing degree of perfection; whereby they have become a valuable acquisition to the navigator, in determining the difference of longitude made in short periods; however, considering the delicacy of their construction, and the various accidents to which they are liable, an implicit confidence ought not to be placed in them, particularly during long voyages; but recourse should be had to astronomical observations, whenever opportunities present themselves.

The various astronomical methods of determining the longitude depend likewise upon the above-mentioned general principle; for, by observing the time at the meridian of a given place when any celestial appearance happens, and comparing the same with the time at Green-

wich, shown by the "Nautical Almanac,"* their difference, reduced to degrees and minutes, gives the longitude as before. Suppose, for instance, that an eclipse of the moon should be observed at a certain place to begin at midnight, and that by the Almanac the time at Greenwich, when the eclipse commenced, was three hours past midnight; now, as the commencement of the eclipse must be seen at the same moment of absolute time in all parts where it is visible, the difference between the time at the place of the observer and that of Greenwich, which is three hours, and answers to 45 degrees, must be the longitude of the place; and it is evidently west, because the time at the place is less than the time at Greenwich. Upon the same principle the eclipses of Jupiter's satellites will give the longitude. But eclipses of the moon happen too seldom to be of use at sea, and the satellites of Jupiter are visible only through a telescope of considerable magnifying power.

The most practical method of finding the longitude, by celestial observations, is that of measuring the angular distance between the moon and sun, or the moon and certain stars near the ecliptic, usually called a *lunar observation.* The moon describes every month an orbit round the earth from west to east, at the distance of about 240,000 miles; in appearance it moves on the celestial

* The "Nautical Almanac" is published annually, by order of the Lords Commissioners of the Admiralty, generally four years forward, and contains 22 pages to each month; in these are entered the sun's longitude, right ascension, declination; the planets' longitudes, latitudes, times of passing the meridian; the times of solar and lunar eclipses, together with those of Jupiter's satellites; the distance of the moon from the sun and certain fixed stars, at the beginning of every third hour; and in general the times when any remarkable appearance takes place, being all computed for Greenwich time. This excellent and most useful work was originally proposed by, and calculated and printed under the immediate inspection of, the late Dr. Maskelyne, Astronomer Royal, and has recently been very much improved and enlarged.

concave in a curve line, near the ecliptic or apparent orbit of the sun. It moves faster than the sun from west to east, by about a degree and a half in three hours. Supposing it to be at the distance of from about 30° to 120° from the sun, either west or east of it, we are frequently enabled to see the two bodies above the horizon at the same time. When this is the case, the distance of the two bodies may be observed with a sextant, and thence the correct distance of their centres, as seen from the earth's centre, which is called their true distance, may be computed. And from this true distance, with the help of the "Nautical Almanac," wherein the true distance (within certain limits) is put down for every third hour, Greenwich apparent time may be easily determined.

I shall here insert an extract from the writings of Captain Basil Hall, R. N.; his familiar style, and, as he terms it, A, B, C method of explaining, being well suited to the youthful student:—

"There are various methods in use for working out this question (the longitude), but I shall mention only two, which have infinitely higher claims to notice than all the rest put together, at least in the practice of navigation.

"One of these is called the method of lunar distances; the other the method of chronometers. That by chronometers is extremely simple. It consists in regulating a watch, constructed upon particular principles, side by side with a clock at Greenwich, so that the two may keep going correctly together—that is, always showing the same hour at the same moment. If this watch, or chronometer, be good of its kind, it will continue to show the same time as the Greenwich clock, under any change of temperature, and in every place to which it may be carried, whether the distance be a few yards, or include the whole circuit of the earth.

"I need scarcely pause to remark, that, in practice, it is a matter of indifference whether the chronometer so carried about from place to place really shows Greenwich time, or whether its daily rate of going, and, consequently, its accumulated error, be known at any stated moment. All that is required of the chronometer is, that it should afford the means (with or without correction) of ascertaining what is the true time at Greenwich at any given moment.

"Supposing our chronometer to possess this property, we have then only to find out, by means of a very simple observation, the true time at the ship at any given instant (that is to say, the sun's distance from the meridian), and carefully to note the exact hour and minute shown by the chronometer, or, which is the same thing, by its old companion, the clock at Greenwich, at that moment. The difference between the ship's time, so found on the spot by actual observation, and the Greenwich time, shown by the chronometer (when reduced to degrees at the rate of 15° to an hour), is the longitude required.

"The method of lunar observations is, in principle, identically the same. The only difference between them consists in the manner of arriving at the results. Dr. Wollaston, in a letter to me, dated 23rd of April, 1826, says:—'The moon is the hand of a great Greenwich clock, seen all over the world, with which you compare the chronometer, to see how it differs, and how it goes. You then compare it with the sun as clock of the place, having by another separate observation determined the latitude.'

"In practice it is easy to press the moon into our service, and make her act as the hand of a Greenwich clock in the sky. The moon, as every one knows, moves, like all the planets and satellites, from west to east, amongst

the stars, and performs the complete circuit of the heavens once in every month—that is to say, she moves to the eastward through the heavens at the average rate of about thirteen degrees a day, or somewhat more than half a degree an hour. Thus her apparent motion amongst the stars is about one minute of space in two minutes of time; and this, which is a rate of movement distinctly perceptible even to the naked eye under some circumstances, is always observable with the instruments in use at sea. The consequence is, that whenever the sky is clear, and the moon up, we can ascertain, at any given moment of time, by actual observation, her exact place in the heavens relatively to the sun, or planets, or stars lying in her path. We then refer to the 'Nautical Almanac,' an ephemeris in which the moon's place has been previously computed by astronomers, and there we discover the Greenwich time at which it has been predicted that she will reach the point in the heavens we have observed her to occupy at the moment of 'taking the lunar,' as it is called. Having likewise ascertained what was the 'ship's time' at the same instant, by other observations made on board, we ascertain their difference by subtracting one from the other (precisely as in the case of the chronometer), and we arrive at the difference of longitude between the ship and Greenwich.

"Dr. Wollaston's remark, that the moon is the hand of a great Greenwich clock in the sky, will now, I think, readily be understood. All that we require of our chronometers, indeed, or of the moon, is, to tell us the time or hour of the day, at Greenwich; while, by means of other instruments, we determine the time, or hour of the day, at the ship at the very same moment. These two times being known, the ship's place on the globe at that moment, so far as longitude is concerned, becomes known likewise, by

simply taking their difference and converting it into longitude, at the rate of 15 degrees to each hour.

"To make this matter perfectly clear, one more illustration will suffice. Let it be supposed that the clock at Greenwich were to strike so loud as to be heard over the whole globe at the same moment (and suppose the allowance for the slow rate of sound out of the question), then any navigator, who had the means of ascertaining by observation the time at his ship, at any given moment, would be able to ascertain his longitude, by comparing the time so found with that derived from hearing the Greenwich clock strike the hour. Now, the moon answers—and answers admirably—the same purpose to the eye as the sound of the clock would to the ear: both give the time of the day at Greenwich, which is all we require to have given us, either by chronometer or by the moon. The rest we can find by observation for ourselves."

In favourable weather, distances between celestial bodies may be taken at all times, when they are more than four or five degrees above the horizon, except about the time of new moon; and as the moon's daily motion is about 13 degrees, or at the rate of 1 minute of a degree in 2 minutes of time, if her true angular distance from the sun or a star can be ascertained within 30 seconds of a degree, the corresponding time at Greenwich will be known within 1 minute of time, and hence the longitude within 15 minutes of a degree.

To facilitate this important problem, the true angular distances of the moon from the sun, or a fixed star,* are

* The stars used in the "Nautical Almanac" for the above purposes are, *a Arietis*, *Aldebaran*, *Pollux*, *Regulus*, *Spica Virginis*, *Antares*, *a Aquilæ*, *Fomalhaut*, and *a Pegasi*. As a knowledge of these stars is of great importance to the observer, Celestial Maps, with directions for using them, have been published; in which the above stars are particularly pointed out, and may be more readily known by comparing the maps with the heavens than

set down in the "Nautical Almanac" for the beginning of every third hour of Greenwich time; and the time answering to any intermediate distance may be found by proportional parts: hence, the distance between these objects being taken with a sextant, and the corresponding time at Greenwich found by the Almanac, and compared with the time at the ship, their difference will be the longitude of the place of observation.

But, before the observed distance is compared with those in the Almanac, it must be corrected, in order to find the true distance; for, by the effects of parallax and refraction, the moon is always seen lower than its true place, and the sun or star higher: hence the true distance is almost always greater or less than the observed.

In taking a *lunar observation*, two assistants should be employed to observe the altitudes of the objects while the principal observer is taking their distance; also one with a watch to mark the times when the observations are made.* If the sun or star be at a proper distance from the meridian, the time may be inferred from its altitude; but if it be too near the meridian, a watch will be absolutely necessary, whose error must be found by an altitude taken before or after the lunar observation, according as it may be most convenient.

The sextants being properly adjusted, and their index-errors found, place the assistants in the most convenient situation, and let the one holding the watch be provided

they possibly can by any verbal description. To be had of J. W. Norie and Co., 157, Leadenhall-street.

* A practised observer may take all the observations without any assistants, by first taking the altitudes of the objects, then the distance, and again their altitudes, and reducing the altitudes to the time of observation of the distance; or, by a single observation of the distance, the time being known from which the altitudes of the bodies may be computed, the longitude may be determined.

with a paper and pencil, to note down the observations when taken: all things being ready, proceed to take the distance between the objects, the assistants at the same time observing the altitudes of each; when this is done, give notice to the assistant with the watch, who is to mark the exact time and set it down, together with the observations read off from the instruments; in this manner proceed four or five times, each set of observations being noted down in proper order: then take the mean of the times and of each observation, by adding them together and dividing their sum by the number of sets observed: the quotient will give the mean of each set, which is much more to be depended upon than if one set only were taken.

Method of observing when the altitudes and distance are taken at the same instant, and the apparent time at the place of observation is obtained from the altitude of the sun or a star.

For the sun and moon.—When the sun and moon are both above the horizon, and within distance (that is, when their distance is put down in the "Nautical Almanac"), bring with the sextant the darkened image of the sun to the moon, without using a telescope; when this is done, clamp the index-plate, put in and adjust the telescope; then by means of the tangent-screw make an exact contact of the nearest limbs.

For a star and the moon.—Bring the image of the moon (darkened if necessary) up to the star; clamp the index-plate, put in the telescope and adjust it; then make the enlightened limb of the moon pass through the middle of the star by means of the tangent-screw.

The following is the usual method of taking down a

set of lunar distances, with the altitudes of the objects observed at the same time, and finding the mean observed distance and altitudes :—

	Times per watch.			Distances sun and moon.			Alts. sun's lower limb.		Alts. sun's upper limb.		
	h	m	s	°	′	″	°	″	°	′	
	3	0	16	91	19	10	37	58	49	58	
		1	25		19	40	37	43	50	15	
		3	10		20	20	37	20	50	28	
Divide by	3	4	51		59	10		121		51	sums.
Means .	3	1	37	91	19	43	37	$40\frac{1}{3}$	50	17	
Index errors . . .				+	2	50	—	1		0	
Observed dist. and alts.				91	22	33	37	$38\frac{1}{3}$	50	17	

When assistance cannot be obtained, one person may take a set of observations in the following order, noting the times by a watch :—1, the altitude of the sun or star; 2, the altitude of the moon; 3, any number of distances; 4, the altitude of the moon; 5, the altitude of the sun or star. Then add together the distances, and the times when they were taken, each of which, being divided by the number observed, will give the mean time and distance: then, to reduce the altitudes to the mean time, say, as the difference of times between the observations is to the difference of their altitudes, so is the difference between the time that the first altitude was taken and the mean time, to a fourth number; which, added to, or subtracted from, the first altitude, according as it is increasing or decreasing, will give the altitude reduced to the mean time.

Example.

Suppose the following observations were taken at the under-mentioned times: required the altitudes of the sun and moon reduced to the mean time and distance.

	Times by watch. h m s		° ′ ″	
	3 25 41	Alt. sun's lower limb	54 5 0	
	28 44	Alt. moon's upper limb	20 3 0	
Mean Time. 3 33 47	32 50	Dist. nearest limbs	73 13 30	Mean Dist. 73 14 3
	33 50	Dist. nearest limbs	73 14 10	
	35 0	Dist. nearest limbs	73 14 30	
	38 20	Alt. moon's upper limb	20 45 0	
	42 4	Alt. sun's lower limb	53 14 0	

	Times. h m s	Altitudes. ° ′	Times. h m s	
1st alt.	3 25 41	54 5	3 25 41	1st altitude.
2nd alt.	3 42 4	53 14	3 33 47	mean time.
Diff. .	16 23 :	51 ::	8 6 :	0° 25′ 13″

First altitude of sun's lower limb .	54 5 0
Reduced altitude of sun's lower limb	53 39 47

	Times. h m s	Altitudes. ° ′	Times. h m s	
1st alt.	3 28 44	20 3	3 28 44	1st altitude.
2nd alt.	3 38 20	20 45	3 33 47	mean time.
Diff. .	9 36 :	42 ::	5 3 :	0° 22′ 6″

First altitude of moon's upper limb	20 3 0
Reduced altitude of moon's upper limb	20 25 6

Hence we obtain the following set of observations :—

Time by watch. h m s	Dist. near limb of sun and moon. ° ′ ″	Alt. sun's lower limb. ° ′ ″	Alt. moon's upper limb. ° ′ ″
3 33 47	73 14 3	53 39 47	20 25 6

The lunar method of finding the longitude requires the utmost exactness on the part of the observers, otherwise a considerable error will be made. The moon moves, as before noticed, at the rate of about a degree in two hours, or one minute of space in two minutes of time. Therefore, if we make an error of one minute in observing the distance between the sun and moon, or between the moon and a star, we make an error of two minutes in time, or thirty miles in longitude at the equator.

By the effect of parallax the moon is always seen lower than her true place, because, from being comparatively near the earth, the apparent depression caused by parallax is a greater quantity than the apparent elevation caused by refraction; while the sun appears higher than its true placc, its great distance rendering parallax of less effect than refraction: hence the true angular distance between those bodies, or between the moon and a star, is always greater or less than the true distence. To facilitate the "clearing of the lunar distance," as obtaining the true distance is called, tables have been furnished by the labours of eminent astronomers, by means of which the calculation required for determining the longitude has been greatly abridged. The "Nautical Almanac" gives the true distances between the sun and moon, the moon and the planets Venus, Mars, Jupiter, and Saturn, as also its distance from certain fixed stars, at the beginning of every third hour, mean time, for the meridian of Greenwich. Having obtained the true lunar distance, the longitude of the place of observation is determined by ascertaining the difference in *time* between the meridian of such place and that of Greenwich; which, being converted into degrees, minutes, and seconds, gives the true longitude. The following rules and example, taken from "Norie's Navigation," will show how the difference in time is obtained.

RULE 1.—Among the true distances of the moon's centre from the sun or fixed stars, which are set down in the "Nautical Almanac," find those two distances on the given day that are next less and greater than the true distance found by observation, which place under it. Take the difference between the true distance and the first of these two distances, also the difference between the two distances; subtract the proportional logarithm of the second difference from the proportional logarithm of the first difference, and the remainder will be the proportional logarithm of a portion of time, which, added to the time that the first of the two distances, taken from the Almanac, was computed for; the sum will be the apparent time, (*i. e.*, the time derived from the sun by observing its transit over the meridian) at Greenwich.

2. Take the difference between the apparent time at Greenwich and the apparent time at the place of observation; convert it into degrees and minutes, and it will give the true longitude: east if the time at the place of observation be greater, but west if the time be less, than the time at Greenwich, reckoned from the apparent noon.

Example.—Apparent time of observatiom, $3^h\ 56^m\ 17^s$.

	° ′ ″		
True lunar distance	79 16 25		
		First Diff.	Pro. Log.
Distance at noon, from Naut. Alm.	79 14 17	0° 2′ 8″	1·9262
		Second Diff.	Pro. Log.
Distance at three o'clock, from N. A.	80 40 7	1 25 50	0·3216
		Proportional logarithm	1·6046

	h	m	s
Proportional part . . .	0	4	28
Time of first distance . .	0	0	0
Apparent time at Greenwich	0	4	28
Do. at place of observation	3	56	17
Difference .	3	51	49 = 57° 57′ 15″ E. long.

Problem 1.—To convert degrees or parts of the equator into time.

Rule.—Multiply the degrees and parts of a degree by 4, beginning at the lowest denomination, and the product will be the corresponding time; observing that minutes multiplied by 4 produce seconds of time, and degrees multiplied by 4 give minutes.

Example.—Let 26° 45′ be reduced to time:—

$$\begin{array}{r} 26^\circ\ 45' \\ 4 \\ \hline 1^h\ 47^m\ 0^s = \text{time required.} \end{array}$$

Problem 2.—To convert time into degrees.

Rule.—Multiply the given time by 10, to which add the half of the product. The sum will be the corresponding degrees.

Example.— Let $3^h\ 4^m\ 28^s$ be reduced to degrees.

$$\begin{array}{rrrr} & h & m & s \\ & 3 & 4 & 28 \\ & & & 10 \\ \hline & 30 & 44 & 40 \\ \text{Half} = & 15 & 22 & 20 \\ \hline \text{Corresponding deg.} = & 46 & 7 & 0 \end{array}$$

It may be remarked that the method of determining longitude by lunar observation is but an approximation thereto; still it is quite sufficient for the purposes of navigation, and may often be made to conduce materially to the interests of geography, as I have already mentioned: hence, although it is not absolutely essential for a military officer to be able to use the large sextant for the same objects as his naval brethren, whose personal safety so constantly depends upon it, yet I would earnestly recommend him to master so much at least of practical astronomy as relates to finding latitude and longitude, whether by day or night; and a very slight study of the heavenly bodies, together with a little practice in using the sextant, will enable him to do so much. No officer should neglect the opportunities of accomplishing this object, which the necessary voyages incidental to his profession so frequently present; and yet it is astonishing to notice the almost total inattention to such matters that generally prevails. On board a common transport it is not unusual to see three or four quadrants or sextants brought on deck between 11 and 12 o'clock, for the meridian observation, and by a little management their owners might easily be propitiated, and induced to teach the military tyro how to take a meridian altitude, and from it to calculate the latitude. They might afterwards be persuaded to assist in showing him how to measure lunar distances, the method of using the lunar tables, and working out the longitude. And how, let me ask, could the tedious days, and often months, spent on shipboard be better, or, indeed, so well employed? At first the learner might find some difficulty in using the sextant on the deck of a vessel, owing to the motion, and his progress would, therefore, of necessity, be slow; but by patience and perseverance, he would in the end over-

come every obstacle, and take delight in an attainment of such practical utility.

To do more than devote a few pages, in order to explain in a familiar manner the principle upon which the longitude is obtained by lunar observation, would be stepping beyond the proper limits of a book on military surveying. I must, therefore, refer the student to such works as Thomson's Horary and Lunar Tables, Norie's, Riddle's, Mackay's, and other treatises on navigation, for full instructions on the longitude, as also for various astronomical problems, lunar tables, and examples *in extenso* of the method of working out "lunars." I may, likewise, mention the tables of the Rev. J. Cape, which were published for use along with the "Nautical Almanac," and are both convenient and portable.

It may be added, that the necessary tables for working out astronomical observations have been brought to great perfection. Such plain rules, also, are given in some of the best treatises on navigation, that any one tolerably versed in arithmetic will find no difficulty in the computations.

MILITARY RECONNOISSANCE.

GENERAL OBSERVATIONS — HEADS OF INSTRUCTION FOR RECONNOISSANCE, WITH EXPLANATORY REMARKS—PRECAUTIONS DURING A MARCH—FORMS OF REPORTS.

When the operations of a campaign are carried on in a country with whose nature, features, and resources a commander is unacquainted, his situation may be compared with that of a man groping his way in darkness: but, if, on the contrary, he possess an accurate knowledge of the surface over which he has to operate, he may act with a boldness and decision that will often ensure success. If the theatre of war be in a semi-barbarous country, the accounts of observing travellers and intelligent natives will often prove of essential service; but if it lie in any country of Europe, the maps and statistical reports, published by authority, will always afford much useful information: in either case, a more particular knowledge, as, for instance, such as relates to the nature of the mountains, rivers, roads, woods, towns, villages, military positions, &c., can only be acquired from personal examination by active and intelligent officers. The process by which this examination is conducted, and the requisite information collected, is termed Military Reconnoissance. This important duty belongs especially to the department of the Quartermaster-General, and the officers employed in it ought to be selected in consequence of their proficiency in military surveying and drawing, as linguists, and for general intelligence and activity.

As there is no kind of service more likely to bring an officer into favourable notice than an able performance of the duty of reconnoissance, it is strenuously urged on young aspirants for staff employment diligently to apply their intervals of leisure, so as to acquire due proficiency in foreign languages, military surveying, and the practice of reconnoitring and framing reports on roads, rivers, and districts of country; and they may thus profitably exercise their attention during tours of pleasure.

The greatest captains of modern days, Frederick, Napoleon, and Wellington, attached the utmost importance to this service, and Napoleon especially, as we gather from the pages of Odeleben's *Rélation circonstanciée de la Campagne de* 1813 *en Saxe;* wherein he gives in detail the organization of the *Bureau Topographique,* under Colonel Bacler d'Albe. Under Wellington the officers of the Royal Staff Corps constituted his *Bureau Topographique,* and were constantly employed under the orders of the Quarter-Master General. There are now at the Horse Guards detailed plans, on a large scale, of the whole of the French territory occupied by the British army during the space of three years after the Waterloo campaign; evidencing the great Duke's attention to this important service, even at a period when he had no reason to think a renewal of hostilities probable.

It is not required of a staff-officer to sketch the whole of the country that he is to reconnoitre; there is not time for this in war; but it is essential that he be perfectly competent to sketch well, to enable him to give the details of the positions, and the principal points of his reconnoissance.*

* In treating this subject free use has been made of the translations from the papers of the late General Bourcet, by Captain W. C. Mayne, whose well-compiled volume has been some years out of print.

To abridge this operation, before proceeding to the ground, he can, from a correct map of the country, fix the situations of cities, towns, and villages, on a scale susceptible of details, and afterwards sketch in the ground, while passing over it.

The *coup d'œil*, or the talent of estimating distances, is of the first importance in reconnoitring; it may be acquired by constantly practising the eye to judge distances, and correcting its errors by afterwards measuring them. The position of the individual, with regard to the sun, makes a considerable difference, and it is necessary to accustom oneself to this difference, to avoid being led into errors by it: when facing the sun objects appear much nearer than when the back is to it. In taking a rapid reconnoissance of mountainous country there are other deceptions to which an unpractised officer is liable: he is apt greatly to *over-estimate* the degree of declivity of any extensive bluff slope, even when seen in profile, and much more when seen in elevation. Again, in looking down a valley he is pretty sure to *under-estimate* the rapidity of descent in its longitudinal slope. Also, when standing on a mountain ridge, we are apt to think a knoll at the end of a spur is higher than our own position, though in reality the knoll is much lower. This deception is often very strong.

A knowledge of fortification, if not absolutely indispensable to officers of the staff, is at least highly useful, as enabling them to report with accuracy upon any fortified places or works which may be in the district they have to reconnoitre; as also upon the facilities that open towns, villages, churches, houses, and buildings of every kind, may present for being fortified or retrenched; to mark likewise the proper sites for throwing up field-works, establishing batteries, &c., and those which from being commanded or

enfiladed from points actually held by the enemy, or which they cannot be kept from occupying, would be improper for such purposes; and to calculate the time, labour, and materials required for the necessary works.

It is indispensable that officers employed on a military reconnoissance should be good linguists generally, and that they should speak the language of the country in which they are to act, fluently and correctly, and write it with accuracy. Without this the information they acquire must be extremely limited, and their reports must be, at best, meagre and unsatisfactory, if not positively incorrect. If entirely ignorant of the language, they must have recourse to interpreters to obtain intelligence from the inhabitants. Questions and answers coming thus at second-hand can never be so full and satisfactory as direct ones; besides which, the interpreters may be either faithless or incompetent; or, without being either, they may not, at the moment, catch the spirit of the interrogation or reply, although they may give a *literal* translation of the *words* employed. We are all aware how much in conversation depends on emphasis and intonation, and how various and widely different are the significations of which a single sentence is susceptible, by placing the emphasis on one word or member instead of another. If but slightly acquainted with the language, they must be constantly liable to have their questions misunderstood, and themselves, in turn, to misunderstand the answers given; whence it follows that their reports can never be depended on with certainty; they *may* be correct, but they *may* be the reverse, and if so, and acted upon as correct, how fatally irreparable may be the results of their errors.

It is often highly useful to an officer to speak, or at least to understand, the *patois* of the peasantry and lower classes in a country, to enable him to communicate freely with

them; as from such persons highly important information respecting fords, bye-ways, passes, &c., is often obtained.

Too much attention cannot be given to the correct spelling and pronunciation of names of places, rivers, &c.; an omission or mistake of a single letter, nay even of an accent, may produce most serious consequences, by the confounding of one road, town, village, &c., with another, which may perhaps lie in a direction altogether different from that intended. It often happens that a person asks a peasant the situation of certain villages as the names are given on the map, and finds that he is altogether ignorant of such places, because his pronunciation of the names is totally different.

The objects of reconnoissance in a country, province, or district are:

The roads and passes.

The rivers, canals, streams, rivulets, and watercourses of every kind; the inundations, sluices, &c.

The bridges and fords.

The mountains, hills, valleys, and defiles.

Towns, villages, hamlets, country houses, churches, and farms.

The forests, woods, hedges, and enclosures.

Cantonments, camps, and positions.—Reports.

RECONNOISSANCE OF ROADS.

It is evident that a country is rendered more or less practicable by the number of roads which intersect it; and it is rarely that a passage can be effected where the inhabitants declare it to be impossible. Attention must be

given not only to the beaten tracks, but also the possibility of opening new routes.

Let an officer commence by examining the main roads, noticing all the roads which join them, and pointing out the bad parts, as well as the labour required to repair them.

If there are any heights commanding the road, the points at, and the distance to which they do so, must be noted, and if they can be turned or avoided, the means by which this can be effected; this remark applies, in like manner, to towns, buildings, military works—in short, to everything lying on, or sufficiently near to, the road, which an active and determined enemy might avail himself of, to dispute the advance of troops.

After having reconnoitred all the main roads, he must examine, with equal care, the others of greatest resort in the country; and, in general, all those leading from one town or village to another; he must particularize the nature of the soil over which each road passes, whether sand, clay, or gravel; he must also learn the state of these roads in the end of autumn and in winter, bearing in mind that the reports of the people are not always to be relied upon. Roads which stand the carriages of the country very well, at the close of autumn often become impracticable when on the line of communication of an army: only those whose bottom is coarse sand, gravel, or stone, continue good throughout the entire year; such as traverse clay, or are sunk between banks, are to a certainty bad after heavy or continued rains. The bye-ways must not be neglected; the inhabitants are apt to consider them impracticable for troops, when a little labour might make them good.

In mountainous countries no exertion must be spared to obtain a knowledge, not only of every road, but as far as possible even of every pass and track; there are few of these which cannot be used by infantry, and such have

often exercised important influence on the issue of a campaign or a movement. Herdsmen, smugglers, foresters, and persons following like occupations, are best acquainted with these passes; from them information should be sought respecting them, and if time admits, under their guidance, they should be carefully examined.

Mention must be made of the breadth of all roads, and particularly of the hollow ways; the length, too, of these latter should be noted, and whether they can be widened by any reasonable labour.

In reporting on roads, the breadth and stability of bridges must be noticed; together with the repairs required to render them fit for the passage of artillery. In hilly and wooded countries, the roads are generally very narrow, and sunk between high banks; the breadth of these roads must be noted, to ascertain with what front troops can march, and whether artillery and wagons can proceed along them.

If possible, hollow ways should be avoided; their bottom is generally bad, and should a single carriage break down on the line of march, the entire column is brought to a halt, and obliged to wait till the vehicle is removed, and thus time, which is of the utmost consequence, is lost.

Distances from point to point along a road must be noted, which should always be calculated in hours of march, for artillery, cavalry, infantry, and convoys, as well as marking the number of leagues or miles. To give the latter only would not be sufficient, as it is evident that the ascents and descents on a road, as well as its condition, will materially affect the rate of moving along it. It often happens that it takes a longer time to go to a place than to return from it, or *vice versa;* when such is the case, it must be noted and stated in the report.

Summary of the points to be attended to in the reconnoissance of roads.

Their direction, their width, the distance in hours of march from point to point, and in leagues or miles: their description, paved or not; on a clay, gravel, or sandy soil; the ascents and descents, and a calculation of the delay resulting from them on a march, whether going or returning; whether practicable at all times, and for what description of troops; running between hedges, ditches, or rows of trees. The rivers, the cities, towns, villages, hamlets, the country, &c., which they traverse; the bridges and fords to be passed; the direction of roads leading from these points, the state of these roads, and the advantages to be drawn from them, or the precautions to be adopted to prevent the enemy availing himself of them; if they can be readily broken up; the heights which command them. Among mountains, if the roads are direct or winding; the slopes where carriages will require drag-chains in descending, or additional horses or oxen in ascending; the bad and narrow parts; the repairs necessary to facilitate the passage of artillery and other troops; if there are hollow ways, the parts to be filled up to avoid accidents to the carriages, which may delay the march of columns; the description of vehicles used in the country, and the length of the axles.

The annexed form of report is that which the late General Sir George Murray had drawn up for the use of the Quarter-Master General's department in the Peninsula. —In some respects it is more convenient when the sketch of a road begins at the bottom, as in that of the road from Malaga to Granada.

RIVERS, CANALS, STREAMS, RIVULETS, AND WATER-COURSES OF EVERY KIND—INUNDATIONS, SLUICES, ETC.—BRIDGES AND FORDS.

Rivers.

LARGE rivers form a principal object in all projects of war, whether offensive or defensive: they cannot be too closely and accurately reconnoitered, to obtain correct information as to the resources they afford, or the obstacles they present.

Before entering into the details of the reconnoissance of a river, it is necessary to mention the different descriptions of country that it traverses in its entire course, and particularly in the part to be reconnoitred.—If it traverses a hilly country, one of fertile plains, or with tracts of heath; if it be enclosed between lofty banks, and confines itself to one channel, or forms several islands; the size of these islands; if they are inhabited, cultivated, or covered with wood. Accurate information must be obtained of the periods when the water rises, and of the extent to which its inundations spread.

All rivers which divide into several branches, and form several islands, are subject to change the main channel of their course at each rise of the water, which may therefore from year to year render all previous reconnoissance useless. Rivers and large streams running through plains are generally sluggish in their course, but almost invariably of considerable depth; those, on the contrary, in a mountainous country, or into which several tributary streams flow from mountains, are rapid and impetuous in their

course, and are subject to sudden rises and falls in their waters, according to the seasons; heavy or long-continued rains, and the thawing of the snow among the mountains, greatly increases their volume, while in summer they are at times so shrunk as to leave their channel almost dry.

The rise in their waters is for the most part periodical, three times in the year; the first in March and April, when the snow begins to thaw; the second in July and August, when the intense heat melts the snow which has remained on the tops of the mountains and in the deep and dark ravines and clefts; and the third at that period of the winter when the heavy falls of rain occur.

It is necessary that the General of an army should be accurately informed of the periods when the waters rise, to enable him with that knowledge to combine the execution of the projects he may entertain to effect or prevent the passage of a river. The degree of steepness of the banks is deserving of particular attention; this must be observed from one bank to the other, and mention made of the height of both above the surface of the water.

The exact knowledge of the banks of a river brings to view, on the offensive, all the points where a passage can be effected; and on the defensive, the points to be guarded, and those which the height and steepness of the banks render impracticable.

Rivers which wind and form many bends in their course, offer more facilities for effecting a passage than those which run direct; since to prevent the passage the enemy has to move round arcs of circles, while his opponent, seeking to effect it, has only their chords to traverse.

Fords.

In all rivers, large or small, there are fords which must be carefully examined. In hilly countries the fords are

often obstructed by large stones; such are very inconvenient for horses, and impracticable for carriages. In countries with cultivated plains, the fords have almost always a gravel bottom; these are the best. In countries with tracts of sand or heath, the fords frequently have quicksands.

A ford, the bottom of which is a fine sand, is dangerous; if a great number of horses are made to pass such, the sand is disturbed, the stream carries it away, and the ford deepens insensibly, so that the last horses pass them almost swimming; and a mud bottom is even worse. In crossing a sandy-bottomed ford, the natives of India hold that cavalry should never go first: a large body of infantry will compact the bottom and improve it, whilst cavalry would destroy it. The depth of a ford must invariably be mentioned: the reports of the peasants must not be trusted to, especially in a hostile country, as to the number in a river; they do not name all, and frequently are only acquainted with those in common use. We are often surprised on learning that bodies of the enemy have passed a river by unused or unknown fords. It sometimes happens that old wheel-tracks entering a river are met with; the water must be sounded in the direction of such tracks, as good fords may possibly be found there. A little labour will often render bad fords practicable.

When a river, the waters of which are low, is seen to run rapidly between two sand-banks, it must be sounded, even when there appears no sign of a track, and the people of the country are not aware of any ford there; it is seldom that any river is not fordable in such a place. The breadth of a ford, its depth, and rapidity of current, must be carefully noted.

The best way to reconnoitre fords, is to descend the river in a small boat, having a sounding line and plummet

to sink three feet: all the fords are thus ascertained, because the motion of the plummet makes you aware when it touches the bottom: the breadth and quality of the fords may thus be determined, and the nature of both banks observed. If a ford occurs at the bend of a river, it must be carefully examined, and a report given of the ground on both sides. If the stream be rapid, a ford for infantry should not exceed three feet, for cavalry four feet, and for artillery two and a half feet.

When a ford is reconnoitred a picket should be set up, to show the height of the water at the time, for a fall of rain or a high wind will often cause it to rise. To guard against danger, a ford should be re-examined whenever troops are to cross by it. The best way to ensure the safe passage of a ford is to set up two ranks of pickets from one bank to the other, and to pass a rope along them to form a defence like the rails of a bridge.

To the details of fords, the means at hand of destroying them should always be added. A ford may be rendered impracticable in a variety of ways:—1st. Harrows laid with their teeth upwards, and fastened down by means of large stones or pickets. 2ndly. If large trees are at hand, place them in the water, with their tops pointing to the opposite side, unless the current is very rapid; in this case they must be placed obliquely towards the stream: they must be ranged across the entire breadth of the ford, and so that there may be no intervals between their tops. 3rdly. The most difficult to execute, but most effectual way, is to dig a trench the entire breadth of the ford. Sometimes it is deemed sufficient to break up with the pickaxe the landing-place at the extremity of the ford; this precaution opposes an obstacle to cavalry, but not to infantry.

Bridges.

An examination and report must be made of all the bridges which are over a river; stating whether of stone or wood; if they can bear artillery; their breadth, and the roads which lead to them on both banks. Each bridge should have a particular detail, and it must be observed which of the banks in its immediate vicinity commands the other, and whether by a retrenchment, or otherwise, it can be secured from attack: this depends entirely on the advantage which the nature of the ground on either bank may give. It is usual, whether on the offensive or defensive, or in winter quarters, to preserve the bridges which, by reason of a decided command over the opposite bank, batteries and retrenchments can secure from the enterprises of the enemy.

It is essential to reconnoitre carefully the bends of a river, as well as the shape of the peninsulas they form; the most *rentrant* points of these bends are the best sites for bridges. It is necessary, therefore, to examine if they are suitable for this purpose, and, in case their banks are too steep, to ascertain if they cannot be sufficiently lowered to form ramps or slopes.

If the height of the banks above the surface of the water exceeds six or seven feet, another place must be sought, as saving time and labour: that is preferable which is nearest to the most *rentrant* point of the bend, because the work required for the slopes to reach the bridge is very tedious, and checks the celerity desirable in the passage of a river. Islands present facilities for the construction of bridges not to be overlooked; an examination and report must therefore be made, as to their extent, escarpment, their commands relatively to the river's banks, &c.

The proper sites for batteries for the protection of a

bridge, are the most salient points of the bends, to keep the enemy as distant as possible, and prevent their disturbing the workmen. Care must be taken that these points are not commanded from any spot on the opposite bank, and that the batteries are not exposed to be taken in reverse. The bends and windings of a river, in fine, requiring more attention than the rest of its course, must be reconnoitred with the greatest care, and a detailed report given of the advantages and obstacles which each bank presents with regard to the passage.

In reconnoitring the course of a river it is necessary to examine and make a report upon all streams which flow into it; noticing their breadth, rapidity of current, and escarpment of their banks; if navigable, and from what points. How inconsiderable soever they may be, the fords and bridges, to as great a distance as possible, must be carefully examined and a detailed report made. Ascertain whether a river is generally frozen in winter, so as to bear carriages, and whether entirely or partly; if the latter, the parts not frozen must be pointed out. It is frequently the case that a river covers the winter quarters of an army; if it freezes, the General has measures to adopt on that account. It is always right to ascertain the breadth of a river, particularly at points where it can be passed (see a simple method of doing this by the pocket sextant, page 95); also notice the nature of the country which borders it, all the roads leading to it, the mountains and hills, their forms, slopes, distance from the river, whether wooded or cultivated; and, if the former, the nature of the wood.

Summary of objects to be observed in examining a river.

1st. Whence it flows, and whither it runs; the nature of the country through which lies its course; the advantages to be derived from it; the quality of its water; its breadth and depth; rapidity of current; its bottom, whether mud, sand, or gravel; whether obstructed by rocks; the mills along its course; the periods of the rise and fall of its water, and extent of inundations; whether affected by tides, and to what degree, together with the point to which the flow of the tide reaches.

2nd. The fords; their situations; the tracks or marks which indicate them; their bottom, whether mud, sand, or gravel; obstructed by rocks, or free from all obstacles; their length and breadth; the depth of water, and whether subject to sudden rises, so as to become impracticable; the approaches to, and débouchés from them.

3rd. The bridges; their approaches; their dimensions; whether of stone, brick, or wood; their débouchés, easy or not; the nature of the roads leading to and from them; whether paved or not; open or with hollow ways, which may be rendered practicable; the communications which the bridges maintain; the readiest means to repair or destroy them; their strength, whether sufficient to bear artillery and convoys; the works necessary to defend them.

4th. The banks; the different degrees of their height and slopes.

5th. The points where bridges may be established, according to the facilities presented by the banks, promontories, islands, the current, the width of the river, and its being sunk or closed in; the vicinity of fords; the materials necessary for the construction of bridges, whether to be procured on the spot, near at hand, or from a distance.

6th. The number of boats to be procured, their form

and size, and the number of men, horses, guns, &c., they can transport.

7th. The navigation; the points from and to which it extends; the season best suited to it; the facilities, dangers, &c., attendant thereon.

8th. The nature of the country which borders on either bank; the mountains, hills, ridges; their command, constant or variable; their slope, form, and distance from the banks; the ravines opening from the river-side, and whether practicable; the nature of the woods on the banks.

9th. The cities, towns, villages, and posts, along or near a river; the strength and extent of each, and distance from the river.

10th. The main and cross roads, the paths and tracks which traverse the country on both sides of the river.

11th. The military positions on both sides, as well those perpendicular as those parallel to the course of the river; the routes for the army, in relation to these positions, and to keeping up the communication and watching the course of the river.

12th. Whether the rivers freeze, entirely, or in part; whether the ice will bear the passage of any, and what kind of troops or vehicles; at what period the ice usually breaks up, and the effect it is likely to have on the bridges.

To the reconnoissance of a river, whether for the offensive or defensive, must be annexed a plan of every angle, bend, or peculiarity in its course, on both sides, which may be favourable for effecting the passage.

A sketch of the river reconnoitred, including the country on both sides, to the distance of three or four miles, should accompany the report; which report is most convenient when in a tabular form, similar to the one annexed to the subject of roads.

MOUNTAINS, HILLS, VALLEYS, AND DEFILES.

Mountains.

Great chains of mountains are the best barriers of a country; there are but few roads among them, and their valleys alone are inhabited and practicable.

In the reconnoissance of mountains the points to be examined and reported on, are:—

Their position, isolated or forming part of a range or chain; their slopes on both sides; the points most important to occupy; their crests and summits; the necks or links connecting them with others; the routes, bye-ways, paths, tracks, and passes; in short, every way of gaining their summits and traversing them in all directions; the form of each mountain, whether crested or table; if cavalry and artillery can pass or act upon it, or infantry alone; covered with wood or barren, rocky, &c.; the small streams; the meadows; the forage; the towns, villages, hamlets, farms, &c.; the positions suitable for camps; the periods at which the passes through and over the mountains are open, or rendered impracticable by snow; the object of occupying or traversing the mountains; the plateaux or table-lands which may prove hurtful or annoying if seized by the enemy; the means of turning the enemy's positions, or of your own being turned by your opponents; if the heights of moderate elevation are practicable and useful to occupy, and if posts of observation or batteries should be established on them; if the strategic base and line of operations can be preserved when the army shall have entered the range of mountains; if the communications with the magazines are short and easy; if exposed to be cut off or interrupted by the enemy; the means to ensure them.

Mountainous and hilly countries, partly cultivated, partly wooded, are the most difficult and tedious to reconnoitre correctly, because on all sides they afford positions, of which, however, there are very few not liable to be turned; they cannot therefore be too closely and accurately reconnoitred. We cannot expect to be able to act with advantage in such countries, unless we have a correct, and if possible, a better knowledge of them than the enemy.

To execute this reconnoissance well, an officer must begin by obtaining a general idea of the country. There is always one part higher than the rest, from which ravines run to the right and left; he must, in the first place, carefully examine this, observing with attention the sources of all the ravines and streams, before entering into the detail of the nature of the country; he must examine and trace the principal ravines and streams as far as possible, carefully noting the number and the situation of all those, from the right and left, which unite with that under his immediate observation.

Hills.

The generality of hills in such a country are covered midway with woods, which are only practicable by the roads, the quality of which must be carefully noted. Roads which are commonly but little used generally run along the summits of hills, these must be followed and carefully examined, even in preference to those which may be in use, ascertaining to what points they lead, and the roads which they cross. Care must be taken to indicate the highest points of a hilly district from which a great extent of country can be seen: this is useful either for the purpose of establishing posts, or of discovering the enemy's movements.

An exact account must be given of such parts of a hilly country as are cultivated, and of the kinds of grain grown; also respecting the quantity of fodder, whether green or dry, which can be drawn from the country.

The Valleys.

Their extent; whether inhabited, cultivated, wooded, intersected by ravines, rivers, streams, &c.; if affording a safe and convenient route for troops; if there is danger of being surrounded or taken at disadvantage in them by the enemy; if the mountains and heights are so distant that the enemy cannot, from their summits, crush or annoy with their fire the troops moving in the valleys.

The Defiles.

Their extent; their direction; running in a straight line, or winding; the time necessary to traverse them; the extent of front, both for cavalry and infantry, with which they can be passed; the direct or circuitous routes along the flanks and rear of the defiles, practicable for cavalry, infantry, artillery, and convoys; the labours, materials, &c., necessary to repair or to render them passable; the posts and batteries to be established to cover a movement; the most favourable position to occupy to protect the passage; the nature of the ground at the entrance of the defiles and at their terminations; how to form in order of battle there; the points at, and the routes by, which we may débouche on the enemy, or arrest his further progress; the troops to be employed for this purpose, and if it may be necessary or useful to throw up works to effect this object.

TOWNS, VILLAGES, HAMLETS, COUNTRY-HOUSES, CHURCHES, FARMS.

Towns.—The principal points to be attended to in respect to a town are—its situation, whether on a hill or in a valley; whether open or enclosed by a wall; whether it is commanded by heights, and within what distance they are; the state of the walls, and, if there are any breaches, notice their length and stituation; the thickness and height of the walls, and whether they have battlements and loopholes; whether there is a rampart, or only a *chemin de rondes* on the walls; whether there are towers or any flank defences; the ditches, whether wet or dry, and their breadth and depth; whether there are any streams which enter and traverse the ditches, and whether, by means of dams, the water can be made to flow into the parts of the ditches which are dry, or to increase the depth where there is water; the gates, their number and condition, and whether there are drawbridges; what kind of fences enclose the gardens and orchards outside the walls, and to what extent they can be rendered available for defence; what labour and expense would be necessary to secure the town against a *coup de main.*

As regards accommodation for troops, &c. The size of towns and villages, and number of inhabitants; the number of houses, as also of churches, convents, or other public buildings; whether the houses are large and commodious, or small and mean; what number of troops could be accommodated in private houses, and what in public buildings; what stabling there is, or other cover for horses; the population, commerce, and manufacture; the resources

in provisions, horses, cattle, workmen, bakehouses, flour-mills.

Many of the above observations apply equally to villages and hamlets. In some parts of Germany, and in Flanders, we find villages that are capable of a good defence, owing to the height and thickness of the walls which encompass the orchards and gardens: the village of Ligny having substantial houses and walled farmyards, the Prussians were enabled to withstand the efforts of Napoleon for several hours during the battle which takes its name from that place.

Country-houses—what the French call châteaux—and detached farms, should be carefully examined, especially in reference to military positions; since by means of barricades, abbatis, and loopholes, they have often been converted into strong forts with very little labour, so far, at least, as to be capable of resisting a *coup de main*. The château of Hougomont, which was nothing more than a gentleman's country-house, with out-buildings, orchard, and gardens, was the most valuable feature of the position at Waterloo, and was held by three hundred British soldiers, against the attacks of a whole division of the French army, after a foreign battalion, which occupied a small wood adjacent to it, had been driven off. The farm of La Haie Sainte also became a little fortress, which would not have fallen into the enemy's hands but for a want of ammunition; it was merely a small Flemish farm establishment, having a good wall round its yard, which being loopholed and well barricaded, four hundred of the German Legion kept it as long as their powder lasted.

Plans or sketches of walled towns, defensible villages, gentlemen's seats, farms, or other detached buildings—if of military value—should always accompany the reports upon them.

FORESTS, WOODS, HEDGES, AND ENCLOSURES.

There are few forests or woods that are not practicable, in many directions, by means of tracks used for conveying timber, besides the regular roads for general purposes.

The principal objects of examination in reconnoitring forests or woods are:—

Their situation and extent; the kind of trees, whether lofty or copsewood; whether generally open, or close and tangled; whether the woods can be turned; the ground on which they stand, whether level, mountainous, undulating, or broken; the width and state of the roads, rides, and tracks by which they are traversed; the points from and to which they lead; the necessity of widening them or of opening others; the parts of forests which are impassable save by the roads, and those which are open and practicable; the towns, villages, hamlets, farms, and the cultivated parts in forests.

In his plan of a forest, an officer should be careful to distinguish on it the parts that are clear from those which are thick and close, and to show the roads plainly. We rarely, indeed never, see a military plan in which these points are attended to; the entire forest is represented alike, the open parts in no way different from the close, while the roads are often lost amongst a profusion of trees.

The nature of the hedges and enclosures of a country is an important object in reconnoissance; the advance of an enemy through a country like England could be impeded at every step, and accounts we have of the warfare in La Vendée show the great difficulty of traversing and subjugating an enclosed country, when it is energetically defended.

CAMPS AND POSITIONS—REPORTS.

In modern warfare, camps and positions have the same meaning in general, since a camp, during operations near the enemy, should always, if possible, be a military position.

An army may encamp in position for a temporary purpose, such as halting during a night, or more, when retreating; may occupy a position for receiving battle; may take up a position permanently, in order to maintain itself in a country, or to cover a district, or the capital of a kingdom.

For whatever purpose an army is placed in position, the following points must be attended to, in a greater or less degree, according to the immediate object of its commander: That it is not commanded in any part, nor liable to be turned; that the guns should cover and command the surrounding country; that the communication between all parts of a position, and with the rear, should be easy, by means of roads or otherwise; and lastly, that there should be an abundant supply of water at hand, as also of wood for fuel and hutting the troops.

When merely encamping for a night or so, it is not usual in modern warfare to do more than form *abbatis*, loophole the houses of a village, barricade farms, and take such other slight precautionary measures as can be effected with little labour; but are, at the same time, sufficient to enable the rearguard to maintain its ground, while the rest of the army decamps.

If the intention of a general who is weaker than his adversary be to resist an attack, no pains should be spared to render his position as strong as time will permit; wherever great natural impediments do not exist, the front

and flanks should be protected by intrenchments and *abbatis*, by scarping slopes, cutting ditches across roads, and, in short, by presenting every possible obstacle to the enemy's approach.

The like measures are necessary when the object of occupying an extensive position is to enable an army to maintain itself permanently. The lines of Torres Vedras furnish the most remarkable instance in the annals of military history of such a defensive system, and their construction did great honour to the engineers of the Peninsular army. It will be of service briefly to describe them here.

To understand the principle on which they were formed, it is only necessary to observe, that Lisbon being situated at the extremity of a peninsula formed by the Tagus and the ocean, an army posted across that peninsula, below the point where the Tagus ceases to be fordable, would bar the approach to the capital. Nature drew the rude outline of a strong defensive position, and art rendered it perfect. A tract of country of thirty miles, extending from the mouth of the Zizandra on the ocean to Alhandra on the Tagus, was modelled into a field of battle; mountains were scarped perpendicularly, rivers dammed, and inundations formed; all roads favourable to the enemy were destroyed, and others made to facilitate the communications of the defenders; formidable works were erected to strengthen and support the weak points; whilst numerous cannon, planted on inaccessible posts, commanded the different approaches, and gave an equality of defence to the whole position. This line, following the inflections of the hills, was twenty-nine miles in length.

A second range of heights, running nearly parallel to the first, at a distance varying from six to ten miles, was fortified in like manner, to retire upon in the event of the

most advanced line being forced; its length exceeded twenty miles.

There was yet another intrenched position, which covered Fort St. Julian, as a last resort, and from whence the army could have embarked.

The second, or middle, of these three lines of works was the most important, and where the great stand was intended to be made; the original object of the first being to check the enemy for a time, and enable the allied army to enter and occupy the second, without hurry or confusion; whilst the third merely afforded a place of refuge, whence to embark unmolested; the works of St. Julian being sufficient to protect the departure of a rearguard.

The exterior line was entered by five roads practicable for artillery, namely, two at Torres Vedras, two at Sobral, and one at Alhandra; and the object of all the redoubts, intrenchments, abbatis, &c., was to bar those passes and to strengthen the ground between them. The right rested, as before observed, upon Alhandra and the Tagus; the ground there being naturally strong and flanked by gun-boats, no fears were entertained in that quarter. The Monte Agraça, a lofty mountain, upon whose summit one large and three small field-works were thrown up, armed with forty-four guns, commanded the country around, and gave great strength to the centre. Torres Vedras was defended by a spacious field-work, and many smaller ones, judiciously placed, so as to command all the approaches.

The lines were armed with six hundred pieces of artillery, planted in situations to sweep the approaches and converge their fire upon the points most open to attack. The troops were indefatigable in strengthening their several positions by every possible contrivance: huge oak and chestnut trees were dug up by the roots and dragged into situations chosen for the formation of *abbatis;* solid stone walls were

built to serve as breastworks; ditches were excavated; and, in short, no measure of defence was neglected which could add to their security.

Having given a description of those celebrated lines, to show what has been effected, I shall now proceed to furnish a few hints with respect to defensive positions in general.

A commander desirous to avoid fighting should take up a favourable position, and strengthen it so that the enemy cannot attack it but at a decided disadvantage.

Particular attention is necessary in the choice of a defensive camp; and the most perfect knowledge, not only of the detail of the ground, but also of its connection and relation with the surrounding country, is required.

The front and flanks of a position should be covered so as to leave but a slight possibility of approaching them; it is necessary that the obstacles which cover the flanks be of a nature not to be turned without making a wide circuit; if there are any marshes, they must be sounded in several places, to ascertain whether they are impassable, and to find out places which may be practicable.

If there are large streams, all the fords must be sounded, not only in the immediate vicinity of the position, but also above and below it.

When the front of a camp is covered by a considerable stream, the bridges and fords, both above and below the position, must be destroyed. Inundations must be formed, which serve not only to keep the enemy at a distance from the position, but also oblige him to make a circuit to reach the flanks.

If there be any thick woods in front or on the flanks of the position, it is not sufficient to reconnoitre them in the immediate vicinity only; the country beyond must be examined to as great a distance as possible, since frequently

when the flanks are covered by very thick woods they may be turned.

It is seldom that positions are found sufficiently strong by nature; it is almost always necessary, in order to strengthen the parts which are accessible, to form intrenchments and *abbatis*, construct redoubts, batteries, &c. For the sites of the latter, small hills, or rising grounds, which are not commanded, should be chosen, so as to bring a cross-fire to bear on the approaches to be defended. The most grazing fire is the best; a plunging fire produces but little effect.

The report of a position must include all the roads leading to it, in front, in rear, and on the flanks, stating their several directions, quality, &c. The names, distances, and size of towns or villages in the vicinity of the camp must also be stated, and a particular notice given of villages which are in front or on the flanks, and fit to be occupied.

It is never a disadvantage for a defensive camp to have a close or intersected country in its rear, provided there are no insurmountable obstacles, and that there is a sufficient number of routes for the retreat of the army. A close country in rear of a defeated army favours its retreat, and a rear-guard is much less exposed than in an open one.

The value of a defensive position does not consist solely in the advantages of ground; a position may be excellent in itself, and yet be of no use; it is an easy matter to find a camp, the front and flanks of which are well protected; such are frequently to be met with in hilly countries; but it is seldom that one can be found which the enemy cannot turn. A defensive position is good only so long as the enemy cannot pass by or turn it, without too much exposing his flank, and laying open his communications.

The position in front of Waterloo is an excellent one; but, had it suited Napoleon's purpose, he might have manœuvred by Hal upon Brussels, which would have compelled the Duke of Wellington to abandon his position.

REPORTS.

In all reports, an officer should state distinctly what parts of the information they contain rest upon personal examination of the objects in question, and what upon the authority of others; in the latter case, the source from which information has been derived should be mentioned, in order that a judgment may be formed of the degree of credit to which it is entitled.

In a hostile country the inhabitants may be expected to endeavour to mislead; but in all countries it is difficult to obtain correct information; the people usually assert that roads in the environs of their villages are impracticable; hoping thereby to keep the troops at a distance from their own dwellings; and they often imagine ploughed land, fences, ditches, &c., to be serious obstacles to the movements of an army.

It is always prudent to avoid putting questions whose tendency is obvious to the inhabitants, and to ask innumerable questions of no importance along with those to which answers are required.

The following heads comprise the principal points on which a report should treat:—

1st. On everything which may impede the movements of an army.

2nd. On what may influence the choice of a position.

3rd. On the resources to be drawn from the country, and the means of securing them, ascertained by the reconnoissance of the district.

4th. The large and small streams and marshes; the forests, with the roads and ravines in them.

5th. The roads of the country in general—the main roads in particular.

6th. The cities, towns, villages, &c.—their defence and resources.

7th. The degree of fertility of the country; the most common kind of provisions, and the general resources in horses, cattle, and forage.

Each object of reconnoissance should be detailed separately, and in its full extent, before entering upon another.

All considerable rivers should have a separate report, distinct from that of the general reconnoissance of the country.

Every position requires a particular report, and should be accompanied by a plan or sketch, on a scale of not less than four inches to a mile. More general sketches may be made upon a scale of two inches to a mile, and tracings of roads upon a scale of one inch to a mile.

OF PRECAUTIONS DURING A MARCH.

No division, brigade, or even considerable detachment, should move without being preceded by an intelligent officer, whose business it is to ascertain the practicability of the route by which the troops are to march; the width, depth, and nature of streams and brooks; the strength and width or bridges, and, if broken or destroyed, what materials are at hand for repairing them (in Spain and Portugal the beams, rafters, and floorings of the large ventas or inns, often supplied the means of effecting this object); the nature of the country, whether hilly or flat, wooded or open, dry or marshy; whether the villages

hamlets, farms, &c., are numerous on or near the route; what parts are suited for cavalry to act; what military positions are met with suited to the strength of the division or detachment which is moving; in short, he should obtain, either by personal inspection or from the inhabitants, minute information upon every point touched on in the foregoing pages. If the march be through a friendly country, the officer need only be accompanied by two or three intelligent dragoons, whom he may send to short distances, right and left of the route, to see the state of lateral roads and tracks, nature of woods, &c. He may be thus employed a day's march ahead of the troops, communicating with them daily, or oftener, as occasion may demand, by means of his dragoons. In an enemy's country, he would require an escort of cavalry for his personal security, and might not be able to precede the march of the troops by more than an hour or two; but, however short the time he may have for his hasty reconnoissance, it must always be of great value.

An officer employed on this duty must make a rough sketch as he proceeds, by taking a succession of bearings, which he may plot at once to a scale of two, three, or four inches to a mile. If he have no surveying compass, he must sketch as well as he can by the eye, and in either case distances may be measured with sufficient accuracy by the paces of his horse. The principal features of the ground on each hand, together with the woods and direction of rivulets and roads, may thus be indicated, roughly and inaccurately it is true, but sufficiently correct for every military purpose; and the length of a day's march may generally be so reconnoitred in from four to seven hours, according as the country is open or enclosed.

The following precautions should be strictly attended to by every officer in command of a body of troops, when

marching in the vicinity of the enemy, or in an enemy's country, irrespective of the reconnoissance as above recommended.

Flanking parties, preceded by skirmishers, must move parallel to the route of the main body, at a distance of a few hundred yards; these must examine closely the villages, woods, hollow ways, farms, &c. If the detachment comprise both cavalry and infantry, the troops should be disposed according to the nature of the ground—in plains the cavalry covering the infantry, in a close country *vice versâ*. When advancing, no opportunity should be neglected of obtaining full information respecting the woods, marshes, roads, streams, bridges, ravines, defiles, and of everything the knowledge of which may be of service in securing a retreat. The officer in command should pay particular attention to the general forms and features of the ground, noticing what parts present positions suited to the number and composition of his force, and where an effectual stand could be made, in order to check the enemy and afford time for other divisions, moving on parallel routes, to retire; if there are hollow ways or defiles, he should determine beforehand the points at which he would post his infantry to facilitate their passage by the cavalry. The heights overlooking defiles should always be crowned by light infantry.

Soon after the British troops landed in Corsica, in 1804, a detachment of 200 men was ordered to march some distance into the interior, and the officer in command having neglected to crown the heights of a defile, bands of undisciplined Corsicans were suddenly perceived, so posted that they could not be dislodged, nor could the detachment either advance or recede. After a parley, the Corsican leader *permitted* our troops to return to the coast. More recently, the Khyber, Tezeen, and other passes between

Peshawur and Cabul, were forced by Generals Pollock, Sale, and M'Caskill, by taking the precaution to have strong parties employed in clearing the heights of the enemy.

Of the following forms for reporting upon routes, the first is the one used in the Peninsula by the Officers of the Quartermaster-General's Department, under Sir George Murray. It is such a report as any intelligent officer, who may have had the advantage of a military education, should be competent to make; and without the information afforded by a report of this description, when circumstances permit the reconnoissance to be made, no body of troops should move. A very exact delineation of the ground is not, of course, expected in the sketch, which is is often hastily made while the troops are in motion; but all distances along the road must be given with as much accuracy as possible; attention, too, must be paid to what has been said a few pages back on the subject of roads, &c. A few bearings taken with a prismatic compass are sufficient to give the general direction of the road, and, the distances along it being measured by the pacing of a horse or otherwise, it may, if convenient, be roughly protracted to a scale. The length of an ordinary march can be carefully measured, and the ground on each side of the road roughly sketched, in the course of a few hours.

It is desirable that sketches to accompany reports on roads should not be drawn to a smaller scale than *one inch to a mile;* yet at times, when such sketches comprise a great extent of road, or, as frequently happens, when two places of importance are connected by several roads, directed on different mountain-passes, fords, bridges, or

intermediate towns, then a smaller scale may be adopted with advantage; since, in such cases, it is to be wished that the eye should embrace at one glance the whole extent of these various routes, as well as of any roads that may connect them transversely, and also the courses of the rivers and direction of the mountains that separate them.

The second form of report here given is intended to meet the foregoing circumstances; and, being necessarily of a more comprehensive character than the preceding, may be considered such a one as ought to be looked for from a Staff Officer. The map to accompany it should be obtained by a rapid triangulation, and the filling-in performed with great care; and as, in most cases, the scale must be far too small to admit of the ground being described with much detail, detached sketches of such portions of the different roads as present difficulties to the movements of troops, or offer military positions, should be given on a larger scale.

A sketch of the nature of that given in the form, which comprises a considerable extent of mountainous country, requires some little time to execute; as the whole of the ground should be carefully gone over, and every pains taken to obtain an accurate knowledge of all its parts.* The report also, besides entering into a minute description of the country to which it especially relates, should furnish good information respecting the communications with places at a distance, and not included within the limits of the sketch. Considering, therefore, the important consequences that hang upon the correctness of the information

* I am indebted for this sketch and report to Lieut.-Colonel C. Rochfort Scott, late of the Royal Staff Corps, who reconnoitred and drew up detailed reports of a very large portion of the province of Andalusia, in Spain—a country of which no maps exist that have any pretension to accuracy. The sketch and report, with which he has so obligingly supplied me, are descriptive of the road lately opened between Malaga and Granada; it is, however, only a part of the reconnoissance extending much further into the country.

required, an officer should have ample time allowed him for the satisfactory discharge of so responsible a duty: for how often have the most brilliantly conceived operations failed from the want of correct information on some apparently trifling point; and how frequently has the whole plan of a campaign miscarried through ignorance of the nature of some particular road: whereas, a general, provided with good plans, and detailed reports on the principal lines of communication through the country which is the seat of war, may act boldly and with vigour, instead of having to feel his way at every step.

In the form annexed, the columns for *distances* contain the measures in English miles; but it is recommended that all distances not ascertained from actual observation, such as lateral communications to towns, villages, &c., should be inserted in the body of the report in the common measures of the country, as received from guides and other persons.

It will be observed, that the plan in question commences at the bottom of the paper, being the manner in which it was drawn in the field: this is in every respect more convenient than beginning at the top. The columns for places, distances, &c., likewise proceed upwards; so that, by following the method here proposed, there need be no limitation to the extent of the sketch and adjoining columns.

REPORT ON MALAGA, AND THE ROAD LEADING FROM THAT CITY TO GRANADA.

1. Malaga is the only port on the south coast of Spain, between Cadiz and Carthagena (a distance of one hundred leagues), whence roads suited to the purposes of an army penetrate into the interior of the country. The harbour of Malaga is formed by a stone pier, that juts upwards of half a mile into the sea in a S.W. direction, and shelters it effectually to the east, the run of the coast protecting it on the opposite side. It is thus well sheltered from the prevailing winds that blow on this coast (due east and west); but is small, and so shallow as to admit only of a few frigates to ride in safety. The entrance is defended by some insignificant batteries, situated on the shore (*à fleur d'eau*) on its western side. At the mole-head is a lighthouse, with a revolving light.

The city itself may be considered as quite defenceless, for of the old Moorish wall that formerly enclosed it but few vestiges remain; and the Gibralfaro, or citadel, built on the crest of a rocky promontory, overlooking both the city and harbour to the N.E., is a heap of ruins. The place covers a considerable extent of ground, and contains numerous large convents, hospitals, and other public buildings, well adapted for magazines and quarters for troops: as also barracks for several thousand men, and abundant stabling. The streets in general are narrow and crooked, but there are several fine open squares in different parts of the town. The houses are good, built chiefly of stone, and several stories in height.

The population of Malaga may be estimated at 60,000 souls, and is on the increase. The inhabitants occupy themselves principally in the preparation of wines and dried fruits, which are exported to an immense amount; but the city contains also numerous manufactories of silk, linen, and hats.

A mountain stream, distinguished by the name of the River Medina, or of Malaga, supplies the city with water. The valley which this rivulet irrigates is very fertile, but the vast plains

Sketched by Major C. Rochfort Scott.

Places &c. upon and near the Road.	Distances. Miles. From Place to Place	Distances. Miles. From point of departure	Accommodation. No. of Houses	Accommodation. Permanent Quarters. Men.	Accommodation. Permanent Quarters. Horses.	Accommodation. Cover for Troops on a march. Men.	Accommodation. Cover for Troops on a march. Horses.
23. Granada	$3\frac{1}{2}$	76	"	.	.	.	"
22. Bridge over the Genil	3	"	"	.	"	.	"
21. Bridge	$1\frac{1}{2}$	.	"	.	"	.	"
20. Santa Fé	8		200	400	100	[illegible]	300
5. Casa-Bermeja	.	"	120	300	100	1000	250
4. El Colmenar	$5\frac{1}{2}$	17	200	400	100	2000	500
3. Venta	$3\frac{1}{2}$	.	1	10	10	30	30
2. Bridge	8	"	"	"	"	"	"
1. Malaga	"	"	"	.	"	"	"

bordering the Guadaljorce (which river falls into the sea about three miles to the west of Malaga) yield the rich crops of corn, maize, hemp, beans, &c., for which the city has ever been celebrated, and render it an admirable point on which to base military operations.

To the east of the city the mountains terminate in rugged ramifications along the sea-shore: the coast, nevertheless, is not so rough but that a wheel-road is practised along it to Velez Malaga, a distance of eighteen miles. The supplies furnished by that town and its fruitful neighbourhood are thus also readily brought into the market of Malaga.

The lofty range of Sierra, that rises at the back of the city, is a ramification of the great mountain-chain of Granada; which, stretching yet many miles further to the west, completes the serrated ridge that borders the Mediterranean shore from the confines of Murcia to the Straits of Gibraltar.

At Malaga, two excellent roads present themselves to cross this difficult, and elsewhere almost impassable, range: the most westerly of these is directed on Antequera (twenty-eight miles), from which city two other wheel-roads, but of a far inferior order, proceed to Seville and Cordoba; at which points respectively they unite with the great road of Cadiz to Madrid. But these roads, though important as opening excellent communications with the lower portion of the valley of the Guadalquivir, proceed too circuitously towards the pass of Despeñaperros—*the only passage across the Sierra Morena, from Andalusia into La Mancha*—to be adapted for military operations against Madrid; especially whilst the direct route from Malaga to the capital is open. This, which is the second of the good roads before alluded to, and the especial subject of this report, proceeds towards the pass of Despeñaperros, by Granada and Jaen; and, whilst operating upon this road, a strong position offers itself for barring the approach to Malaga, by that from Antequera (should it be necessary), about five miles from the last-named city, at the pass of Cauche. (See sketch.)

From the asperity of the country between Malaga and Granada, the great road is unavoidably circuitous, being directed in the first instance on Loja, which town, though nearly north of Malaga, lies due east of Granada. A much more

direct road offers itself between the two places, by way of Alhama, but it is a mere mule track, and, moreover, so completely cut off from the main road by impracticable mountains as not even to be available to move a column of infantry upon, simultaneously with the other (with a view of forming a junction on the north side of the mountains), if in the presence of an enemy.

The main route traverses a very elevated range of country, but is so good as to be throughout, and at all seasons, travelled by a diligence. It begins to mount a rude ramification of the distant mountain range that divides the river Genil from the Mediterranean Sea, immediately on leaving Malaga, ascending by a gradual slope and innumerable windings, until it has attained the summit of the inferior ridge. This it accomplishes at the distance of four miles from the city, and is thenceforth carried along the crest of this narrow mountain spine, ascending gradually to a yet greater elevation, and looking down on cultivated valleys on either side; the steep acclivities of the ridge itself being planted with vines and olive-trees.

2. At eight miles from Malaga, the summit of the ridge widens considerably, and a lofty conical mound here rising up, and protruding some way into the valley on the left, offers a strong position for checking any further advance along the road.

The road is conducted round the eastern base of this mound, the fall of which is so abrupt as to have rendered a bridge necessary to get round the head of a deep ravine that furrows the side of the range. The destruction of this bridge would occasion great delay under any circumstances, as, from the steep and rugged nature of the ground, it would be a work of considerable time to practise a road in the side of the mountain.

The position, before alluded to, may be turned by moving round its right flank; but it would render a somewhat wide movement necessary, which, if successful to the fullest extent, would obtain no further result than that of rendering the position untenable, as the road of retreat for its defenders goes off from its left.

3. The road having passed round this hill again attains the summit of the ridge, and in three miles and a half reaches a

lonely venta, or road-side public-house, the only habitation that has thus far presented itself. From hence the summit of the ridge becomes indented with rocky eminences, but the road is more level than heretofore, and keeps generally on the eastern side of the chain; whence it overlooks a wide extent of extremely intricate and broken country, which is chiefly planted with vines. At three miles there is another house, and two miles beyond this the road descends rather rapidly to El Colmenar. The elevated ground above this town affords a fine position for barring the road in either direction, but especially on the side of Malaga, where the approach would be exposed to an enfilading fire for the distance of a mile. A sketch of the ground on a large scale, and a detailed report on this position, are hereunto annexed.*

4. The road merely skirts El Colmenar, leaving it on the right hand. The town stands on a steep acclivity, and is encompassed on all sides by vineyards. There is a great want of wood in the neighbourhood, and the place is but indifferently supplied with water. The houses are good, and from the quantity of wine collected here the place contains many large storehouses. The population amounts to fifteen hundred souls.

5. There is a road from hence to Casabermeja, a large village situated in the valley on the left of the great route, and distant about four miles and a half from El Colmenar. From Casabermeja this cross road continues on to the pass of Cauche (before mentioned), where it falls in with the Chaussée from Malaga to Antequera. Artillery may be moved along this road without much difficulty, though it is not considered a wheel-road; it thus serves as a useful connecting link between the two great routes.

The road continues to descend for upwards of a mile from El Colmenar, keeping along a low neck of land that connects the ridge the road had hitherto traversed with a far more elevated range of mountains that rises to the north. The ascent towards this lofty sierra now commences, and for two miles is very steep; the road, on attaining about one-third the height of the mountain, turns abruptly to the right, and keeps for four miles and a half under a perfect wall of precipitous rock, that offers a most formidable position. It is one, however, which, if turned

* Not given here.

on its left, would leave its defenders no retreat. A separate report on this position is annexed.*

6. About half a mile beyond where this ridge terminates to the east, is the solitary venta Dornejo, which, being usually made the resting-place of the muleteers and carriers between Malaga and Loja, is abundantly furnished with stabling.

7. Beyond this the mountains are tossed about in curious confusion, and the road, descending for a mile and a half, passes within musket-shot of the small village of Alfarnatejo, situated in a valley on the right.

8. A mile beyond this the road reaches the venta of Alfarnate, a small house, but abundantly furnished with stabling. Both this venta and the village of Alfarnatejo are well supplied with water, and the rough sides of the surrounding sierras now begin to be wooded.

9. A mile beyond the venta of Alfarnate, the village of that name is left three-quarters of a mile off on the right. This little place is watered by a fine stream, and has some cultivated ground in its vicinity.

In the three succeeding miles the road traverses a very difficult pass, which, though not so elevated as many parts of the ridge hitherto travelled, is in the principal mountain chain that runs through the country; the streams henceforward falling northward to the Genil. The pass is overhung by rocky precipices, and is thickly wooded with cork, oak, and ilex.

The numerous springs, abundant wood, and salubrity of this elevated district, render it an eligible site either for the formation of a camp of observation, or to move the troops to from Malaga during the autumn months; when that city and the places in its neighbourhood are frequently visited by yellow and typhus fevers, which occasion a great mortality amongst such of the inhabitants as have not the means of removing beyond their influence.

10. At the northern foot of the pass a small venta presents itself, situated on the bank of a copious stream, over which there is a good stone bridge.

The road from hence is conducted along the valley watered by this stream, and is practised in the side of a lofty mountain

* Not given here.

that overhangs it on the right. It proceeds in this way the whole distance to Loja (twelve miles), and is tolerably easy throughout, excepting for the space of a mile, about a league beyond the venta; the mountain there presses upon the stream and renders its bank very precipitous. The road is carefully made, however, being carried in easy zigzags along the rocky edge of the torrent.

11. At nine miles from the bridge and venta a road joins in on the left, from Antequera. This is the great road from Seville to Granada; and, excepting for the last three leagues, when it traverses a very mountainous country, is a tolerable carriage road. On this latter portion of it artillery could only be moved with great labour.

12. The town of Loja is situated under the northernmost point of the mountain, along the side of which the road is conducted, and which here falls very abruptly along the left bank of the river Genil. A rugged mountain falls equally precipitously along the opposite bank of the river; confining the stream, both above and below Loja, to a very narrow gorge.

The town occupies the widest part of this defile, but the houses are piled in steps, as it were, up the steep acclivity against which they rest, and the place thus completely closes the narrow passage. An old castle (in ruins) overlooks the town, and is itself looked into from the mountain at its back.

A good stone bridge, which, though narrow, is passable for every description of carriage, affords the means of crossing the Genil at all seasons, and communicates with a suburb on the right bank.

Traversing the bridge, a road proceeds to Alcala la Real, offering a much shorter road to reach Madrid than that by way of Granada; but for the first twenty miles this cross road is impracticable for artillery.

Loja has ever been celebrated as a military post of much importance, from the command it possesses of the only entrance on the western side of the fertile Vega of Granada; and although now undefended by walls, and receiving but slight protection from its dilapidated castle, it is, nevertheless, from its strong position, still a very defensible place. It contains four large convents, four hospitals, and a population of nine

thousand souls. The country in its neighbourhood is extremely fruitful, producing corn, wine, oil, hemp, flax, and vegetables of all sorts. Wood and water are also plentiful.

The road to Granada takes an easterly direction on leaving Loja, keeping for yet two miles under the precipitous sierra that there overhangs the left bank of the Genil. It then reaches a small and highly-cultivated plain, watered by a fine stream, and a mile and a half further on arrives at the Venta del Pulgar, in the vicinity of which are several water-mills.

13. The venta is small, but has abundant accommodation for horses. Beyond it the road becomes rather heavy, and is particularly lonely, there not being any village upon it, nor even near it, for many miles. The ground is hilly, but very fertile, the sandy soil of the upper grounds producing corn; the alluvial deposit of the valley of the Genil, millet, Indian corn, hemp, &c., as well as pasturage, which henceforth is very abundant.

The Genil winds through a very level tract of country, and keeps generally at the distance of about a mile from the road; it sometimes, however, approaches much nearer. The character of this stream is the same during the whole of its course through the Vega of Granada; its banks are low and earthy, its bottom muddy, rendering it dangerous to pass without a good knowledge of the different fords, changes in which are constantly effected by the winter torrents. The summer depth of water seldom exceeds three feet, and the current is sluggish; but in winter, and even during the autumnal rains, the stream is apt to rise very suddenly, and frequently overflows its banks, laying the country under water to a considerable extent. These freshets at times rush down with such violence as to do much mischief, as well to the banks of the river as to the crops upon the plain.

14. At eight miles from the Venta del Pulgar, the village of Tajar is seen about a mile off the road on the left. It stands on the northern bank of the Genil, to cross which there is a ferry-boat, capable of passing over horses, or even light artillery when detached from the limbers.

15. At nine miles, the road fords the Cacin. This stream comes down from the sierra of Alhama, and is at all seasons

abundant. In winter it flows with great velocity, but is always passable: the bottom is hard and pebbly.

On the right bank of the stream stands the Venta de Cacin, a solitary house containing plenty of accommodation for horses.

16. Another ferry-boat, similar to the former, offers itself for crossing the Genil a mile beyond the venta, and about the same distance from the road. This ferry communicates with the village of Villa Nueva de Mesia, situated on the north bank of the river.

The country continues hilly all the way to Lachar, a distance of nine miles from the Cacin, and the road is still gravelly and heavy. The soil of the low grounds is particularly productive, but the crops are by no means fine on the uplands. Those grounds, however, are well suited to the vine and olive.

17. Lachar is a miserable village, but, being a post station, as well as a half-way resting-place for carriers, &c., between Loja and Granada, and being also principally inhabited by agriculturists, it contains abundant stabling. The vicinity of the Genil (which flows within two hundred yards of the place), and the quantity of grain produced in its neighbourhood, render Lachar an eligible cavalry station. Wood, however, is scarce.

Beyond Lachar the country on the right of the road becomes much more accessible, and may be considered as suited in every respect to the movements of an army; for though the roads traversing it, owing to the little use made of carts for agricultural purposes in this country, are narrow—in fact, mere mule-tracks—yet artillery, waggons, &c., may be moved across it without difficulty, and a good communication may now readily be opened with the mountain road from Malaga to Granada, by way of Alhama. Indeed the village of Chimeneas, which is on one branch of that road, is but a mile and a half from Lachar, nearly south.

18. About a mile from Lachar a road strikes off to the left, passes the village of Cijuela, and crosses the Genil by a good ford at the hamlet of Fuente Vaquero, proceeding thence to the *Casa real del Soto de Roma*,* where it branches off either to Piños de la Puente, on the road from Granada to Cordoba, or

* On the Duke of Wellington's property.

Granada, keeping along the right bank of the Genil. Both these roads are passable for carriages of every description.

19. From Lachar to Santa Fé is eight miles. The miserable village of Chauchina is situated about a mile to the left of the road, two miles before reaching the last-named town. The road is nearly level throughout, and traverses the heart of the proverbially fertile Vega of Granada.

20. Santa Fé, though dignified with the title of city, is but a small walled village, containing two hundred houses, which, though mostly large, are in a ruinous condition.

The shape of the town is a perfect square. Its walls are four feet thick and twenty-five feet in height, and are flanked by projecting towers. Whilst, from the level nature of the country in the vicinity, Santa Fé thus offers a good *point d'appui* for infantry, yet its walls could make no prolonged resistance to artillery. It is badly supplied with water, and quite destitute of wood.

21. At a mile and a half from Santa Fé the road crosses a rivulet by a stone bridge;

22. And three miles beyond reaches the Genil, which it passes by a solid stone bridge of several arches.

The road now continues along the right bank of the river to Granada, a distance of three miles and a half, and is perfectly level throughout.

COMPARISON

OF

ENGLISH AND FRENCH

MEASURES AND WEIGHTS.

		Mètres.
The English mile of 1760 yards - - -	=	1609 ·31
The imperial yard - - - - - -	=	0·9143
The foot - - - - - - - -	=	0·3047
The pint, or 1-8th of a gallon = in *litres* -	=	0·5679
The pound troy = in *kilogrammes* - -	=	0·3730

EUROPEAN MEASURES.

GERMANY.

		Mètres.
The geographical mile, 15 to a degree -	=	7419·34

AUSTRIA.

The mile, of 10,000 paces, or 4000 toises of Vienna	=	7586·40
The Vienna foot - - - - - -	=	0·316

PRUSSIA.

The mile, according to Hoyer - - - -	=	7747·42

SAXONY.

The mile - - - - - - - -	=	9271·00
The Dresden foot - - - - - -	=	0·283

BAVARIA.

The mile, according to Hoyer - - - -	=	7876·06

HANOVER.

The mile, according to Hoyer - - - -	=	10587·93
The foot - - - - - - - -	=	0·292

SWEDEN.

		Mètres.
The mile, of 18,000 Swedish alner - -	=	10687·00
The Swedish foot - - - - - -	=	0·296

BRABANT AND POLAND.

The mile, of 20 to a degree - - -	=	5564·50

RUSSIA.

The verst, of 500 toises, or 1500 acchinis -	=	1066·77
The foot - - - - - - - -	=	0·355

SWITZERLAND.

The mile - - - - - - - -	=	7386·00
The Basle and Zurich foot - - -	=	0·300

SPAIN.

The league (new), or 8000 vares of 16·6 to a degree - - - - - -	=	6689·00
The league (legal), of 500 vares of Lopez, of 26·5 to a degree - - -	=	4173·00
The Spanish foot - - - - - -	=	0·278

PORTUGAL.

The league, of 18 to a degree - - -	=	6173·00

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APPENDIX.

TABLES

FOR COMPUTING THE ALTITUDE.

BY W. H. JONES, OPTICIAN, 4, RUPERT STREET, HAYMARKET.

TABLE I. contains the Approximate Altitude, in feet, corresponding to the Reading of the Barometer, which should be corrected for capacity and neutral point; for which see page 248 of Treatise.

TABLE II. (page 9) contains the correction for the Mean of the Temperature of the Air at the two Stations, and is found at the head of the column when above 32°, and at the foot when below; and is to be added when above, and deducted when below 32°. The mode of Computation is as follows:—

Example 1, *the Mean Temperature being above* 32°.

	Thermometer. Degrees.	Barometer. Inches.		Feet.
Upper Station..	54	22·93	Approximate Altitude from Table I...	7,858
Lower Station..	66	30·00	ditto ditto........	854
				7,004
Correction for the mean temperarure 60° Faht. from Table II. ...... Add...				406
			Altitude..........	7,410

Example 2, *the Mean Temperature being below* 32°.

	Thermometer. Degrees.	Barometer. Inches.		Feet.
Upper Station..	16	22·93	Approximate Altitude from Table I...	7,858
Lower Station..	32	30·00	ditto ditto........	854
				7,004
Correction for the mean temperature 24° Faht. from Table II..... Deduct..				119
			Altitude..........	6,885

TABLE III. (page 11) contains the Approximate Altitude, in Metres, corresponding to the Centimetres read off on the French Barometer Scale.

In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.
10·00	29517	10·50	28243	11·00	27025	11·50	25863	12·00	24750	12·50	23682
·01	29494	·51	28219	·01	27002	·51	25841	·01	24729	·51	23662
·02	29467	·52	28195	·02	26980	·52	25820	·02	24709	·52	23643
·03	29441	·53	28169	·03	26956	·53	25797	·03	24687	·53	23621
·04	29416	·54	28144	·04	26933	·54	25774	·04	24665	·54	23600
10·05	29389	10·55	28119	11·05	26909	11·55	25751	12·05	24643	12·55	23579
·06	29363	·56	28095	·06	26889	·56	25729	·06	24621	·56	23559
·07	29337	·57	28073	·07	26864	·57	25706	·07	24599	·57	235 8
·08	29311	·58	28052	·08	26838	·58	25684	·08	24578	·58	23518
·09	29284	·59	28023	·09	26803	·59	25660	·09	24555	·59	23496
10·10	29257	10·60	27994	11·10	26789	11·60	25636	12·10	24533	12·60	23474
·11	29232	·61	27970	·11	26766	·61	25615	·11	24512	·61	23454
·12	29208	·62	27947	·12	26744	·62	25594	·12	24492	·62	23435
·13	29182	·63	27922	·13	26720	·63	25571	·13	24470	·63	23414
·14	29156	·64	27897	·14	26697	·64	25549	·14	24448	·64	23393
10·15	29130	10·65	27872	11·15	26673	11·65	25526	12·15	24427	12·65	23372
16	29105	·66	27848	·16	26650	·66	25506	·16	24406	·66	23352
·17	29079	·67	27823	·17	26626	·67	25481	·17	24384	·67	23331
·18	29053	·68	27799	·18	26603	·68	25459	·18	24362	·68	23311
·19	29026	·69	27773	·19	26578	·69	25435	·19	24340	·69	23290
10·20	28999	10·70	27748	11·20	26554	11·70	25412	12·20	24318	12·70	23269
·21	28974	·71	27725	·21	26531	·71	25390	·21	24297	·71	23248
·22	28949	·72	27702	·22	26509	·72	25369	·22	24277	·72	23228
·23	28924	·73	27678	·23	26486	·73	25346	·23	24255	·73	23207
·24	28899	·74	27654	·24	26463	·74	25324	·24	24234	·74	23187
10·25	28873	10·75	27629	11·25	26439	11·75	25302	12·25	24212	12·75	23166
·26	28848	·76	27604	·26	26416	·76	25280	·26	24191	·76	23146
·27	28823	·77	27580	·27	26393	·77	25258	·27	24170	·77	23125
·28	28798	·78	27558	·28	26370	·78	25236	·28	24149	·78	23105
·29	28771	·79	27530	·29	26346	·79	25212	·29	24126	·79	23083
10·30	28745	10·80	27505	11·30	26322	11·80	25189	12·30	24104	12·80	23062
·31	28720	·81	27482	·31	26300	·81	25168	·31	24084	·81	23042
·32	28696	·82	27459	·32	26278	·82	25147	·32	24064	·82	23023
·33	28670	·83	27434	·33	26254	·83	25125	·33	24043	·83	23003
·34	28645	·84	27410	·34	26231	·84	25103	·34	24022	·84	22983
10·35	28620	·85	27386	11·35	26208	11·85	25081	12·35	24000	12·85	22962
·36	28595	·86	27362	·36	26185	·86	25059	·36	23979	·86	22942
·37	28569	·87	27338	·37	26162	·87	25037	·37	23958	·87	22922
·38	28534	·88	27314	·38	26139	·88	25015	·38	23937	·88	22902
·39	28518	·89	27289	·39	26115	·89	24992	·39	23915	·89	22880
10·40	28492	10·90	27264	11·40	26092	11·90	24969	12·40	23893	12·90	22859
·41	28468	·91	27241	·41	26070	·91	24948	·41	23872	·91	22840
·42	28444	·92	27218	·42	26048	·92	24927	·42	23852	·92	22821
·43	28419	·93	27194	·43	26025	·93	24905	·43	23831	·93	22800
·44	28394	·94	27170	·44	26002	·94	24883	·44	23810	·94	22780
10·45	28369	10·95	27146	11·45	25979	11·95	24861	12·45	23789	12·95	22760
·46	28344	·96	27123	·46	25956	·96	24839	·46	23768	·96	22740
·47	28319	·97	27099	·47	25933	·97	24817	·47	23747	·97	22720
·48	28294	·98	27075	·48	25910	·98	24795	·48	23726	·98	22700
·49	28268	·99	27050	·49	25886	·99	24772	·49	23704	·99	22678

In. dec.	Feet.	In. dec	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.
13·00	22657	13·50	21671	14·00	20720	14·50	19802	15·00	18916	15·50	18062
·01	22638	·51	21652	·01	20702	·51	19784	·01	18899	·51	18045
·02	22619	·52	21634	·02	20684	·52	19767	·02	18881	52	18028
·03	22598	·53	21614	·03	20665	·53	19749	·03	18864	·53	18011
·04	22578	·54	21595	·04	20646	·54	19731	·04	18847	·54	17994
13·05	22558	13·55	21575	14·05	20627	14·55	19713	15·05	18829	15·55	17978
·06	22539	·56	21556	·06	20609	·56	19695	·06	18812	·56	17961
·07	22518	·57	21536	·07	20590	·57	19677	·07	18795	·57	17944
·08	22498	·58	21517	·08	20572	·58	19659	·08	18778	·58	17927
·09	22478	·59	21497	·09	20553	·59	19641	·09	18760	·59	17911
13·10	22458	13·60	21478	14·10	20534	14·60	19623	15·10	18743	15·60	17894
·11	22438	·61	21459	·11	20516	61	19605	·11	18726	·61	17878
·12	22419	·62	21440	·12	20498	·62	19587	·12	18709	·62	17861
·13	22399	·63	21421	13	20479	·63	19569	·13	18691	·63	17844
·14	22379	·64	21402	·14	20461	·64	19552	·14	18674	·64	17827
13·15	22359	13·65	21383	14·15	20442	14·65	19534	15·15	18657	15·65	17811
·16	22339	·66	21364	·16	20424	·66	19517	·16	18640	·66	17794
·17	22319	·67	21345	·17	20405	·67	19497	·17	18623	·67	17777
·18	22300	·68	21326	·18	20387	·68	19478	·18	18605	·68	17761
·19	22279	·69	21306	·19	20368	·69	19461	·19	18588	·69	17744
13·20	22258	13·70	21286	14·20	20349	14·70	19444	15·20	18571	15·70	17728
·21	22239	·71	21268	·21	20331	·71	19427	·21	18554	·71	17711
·22	22220	·72	21250	·22	20314	·72	19410	·22	18537	·72	17695
·23	22200	·73	21231	·23	20295	·73	19392	·23	18520	·73	17678
·24	22180	·74	21212	·24	20276	·74	19374	·24	18503	·74	17662
13·25	22160	13·75	21192	14·25	20258	14·75	19356	15·25	18485	15·75	17645
·26	22141	·76	21173	·26	20240	·76	19339	·26	18468	·76	17628
·27	22121	·77	21154	·27	20221	·77	19321	·27	18451	·77	17612
·28	22102	·78	21135	·28	20203	·78	19304	·28	18434	·78	17595
·29	22082	·79	21115	·29	20184	·79	19285	·29	18417	·79	17579
13·30	22062	13·80	21096	14·30	20166	14·80	19267	15·30	18400	15·80	17562
·31	22042	·81	21077	·31	20148	·81	19249	·31	18383	·81	17546
·32	22023	·82	21059	·32	20130	·82	19232	·32	18366	·82	17529
·33	22002	·83	21040	·33	20112	·83	19214	·33	18349	·83	17513
·34	21982	·84	21022	·34	20094	·84	19197	·34	18332	·84	17496
13·35	21963	13·85	21003	14·35	20075	14·85	19179	15·35	18315	15·85	17480
·36	21945	·86	20984	·36	20057	·86	19162	·36	18298	·86	17464
·37	21925	·87	20965	·37	20039	·87	19144	·37	18281	·87	17447
·38	21906	·88	20946	·38	20021	·88	19127	·38	18264	·88	17431
·39	21885	·89	20926	·39	20002	·89	19109	·39	18247	·89	17414
13·40	21865	13·90	20907	14·40	19984	14·90	19091	15·40	18230	15·90	17398
·41	21846	·91	20889	·41	19966	·91	19074	·41	18213	·91	17381
·42	21828	·92	20871	·42	19948	·92	19057	·42	18196	·92	17365
·43	21808	·93	20852	·43	19929	·93	19039	·43	18179	·93	17348
·44	21788	·94	20833	·44	19911	·94	19022	·44	18162	·94	17332
13·45	21769	13·95	20815	14·45	19893	14·95	19004	15·45	18146	15·95	17316
·46	21750	·96	20796	·46	19875	·96	18987	·46	18129	·96	17300
·47	21730	·97	20777	·47	19857	·97	18969	·47	18112	·97	17284
·48	21711	·98	20758	·48	19839	·98	18952	·48	18095	·98	17267
·49	21691	·99	20739	·49	19820	·99	18934	·49	18078	·99	17251

In. dec.	Feet.	In. dec	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.
16·00	17234	16·50	16432	17·00	15655	17·50	14899	18·00	14165	18·50	13451
·01	17218	·51	16416	·01	15640	·51	14884	·01	14151	·51	13437
·02	17202	·52	16401	·02	15624	·52	14870	·02	14137	·52	13423
·03	17186	·53	16385	·03	15609	·53	14855	·03	14122	·53	13409
·04	17170	·54	16369	·04	15593	·54	14840	·04	14107	·54	13395
16·05	17153	16·55	16353	17·05	15578	17·55	14825	18·05	14093	18·55	13381
·06	17137	·56	16338	·06	15563	·56	14810	·06	14078	·56	13367
·07	17120	·57	16322	·07	15548	·57	14795	·07	14064	·57	13353
·08	17104	·58	16306	·08	15532	·58	14780	·08	14050	·58	13339
·09	17088	·59	16290	·09	15517	·59	14765	·09	14035	·59	13325
16·10	17072	16·60	16275	17·10	15502	17·60	14751	18·10	14021	18·60	13311
·11	17056	·61	16259	·11	15487	·61	14736	·11	14006	·61	13297
·12	17040	·62	16243	·12	15472	·62	14721	·12	13992	·62	13283
·13	17024	·63	16228	·13	15456	·63	14707	·13	13978	·63	13269
·14	17008	·64	16212	·14	15441	·64	14692	·14	13963	·64	13255
16·15	16991	16·65	16197	17·15	15426	17·65	14677	18·15	13949	18·65	13241
·16	16975	·66	16181	·16	15410	·66	14662	·16	13934	·66	13227
·17	16959	·67	16165	·17	15395	·67	14647	·17	13920	·67	13213
·18	16943	·68	16149	·18	15380	·68	14633	·18	13906	·68	13199
·19	16927	·69	16134	·19	15365	·69	14618	·19	13892	·69	13185
16·20	16911	16·70	16118	17·20	15350	17·70	14603	18·20	13877	18·70	13171
·21	16895	·71	16102	·21	15335	·71	14588	·21	13863	·71	13157
·22	16879	·72	16087	·22	15320	·72	14574	·22	13849	·72	13143
·23	16862	·73	16071	·23	15304	·73	14559	·23	13834	·73	13129
·24	16846	·74	16056	·24	15289	·74	14545	·24	13820	·74	13115
16·25	16830	16·75	16041	17·25	15274	17·75	14530	18·25	13806	18·75	13102
·26	16814	·76	16025	·26	15259	·76	14515	·26	13792	·76	13088
·27	16798	·77	16009	·27	15244	·77	14500	·27	13777	·77	13074
·28	16782	·78	15994	·28	15229	·78	14486	·28	13763	·78	13060
·29	16766	·79	15978	·29	15214	·79	14471	·29	13749	·79	13046
16·30	16750	16·80	15963	17·30	15199	17·80	14456	18·30	13734	18·80	13032
·31	16734	·81	15947	·31	15184	·81	14442	·31	13720	·81	13018
·32	16718	·82	15931	·32	15169	·82	14427	·32	13706	·82	13004
·33	16702	·83	15916	·33	15154	·83	14413	·33	13692	·83	12990
·34	16686	·84	15901	·34	15139	·84	14398	·34	13678	·84	12977
16·35	16670	16·85	15885	17·35	15124	17·85	14383	18·35	13663	18·85	12963
·36	16654	·86	15870	·36	15109	·86	14369	·36	13649	·86	12949
·37	16638	·87	15854	·37	15094	·87	14354	·37	13635	·87	12935
·38	16623	·88	15839	·38	15079	·88	14339	·38	13621	·88	12922
·39	16607	·89	15823	·39	15064	·89	14325	·39	13607	·89	12908
16·40	16591	16·90	15808	17·40	15049	17·90	14311	18·40	13592	18·90	12894
·41	16575	·91	15793	·41	15034	·91	14296	·41	13578	·91	12880
·42	16559	·92	15777	·42	15019	·92	14281	·42	13564	·92	12866
·43	16543	·93	15762	·43	15004	·93	14267	·43	13550	·93	12852
·44	16527	·94	15747	·44	14989	·94	14252	·44	13536	·94	12839
16·45	16511	16·95	15731	17·45	14974	17·95	14238	18·45	13522	18·95	12825
·46	16495	·96	15715	·46	14959	·96	14223	·46	13508	·96	12811
·47	16480	·97	15700	·47	14944	·97	14209	·47	13493	·97	12797
·48	16464	·98	15685	·48	14929	·98	14194	·48	13479	·98	12784
·49	16448	·99	15670	·49	14914	·99	14180	·49	13465	·99	12770

In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.
19·00	12757	19·50	12080	20·00	11420	20·50	10776	21·00	10148	21·50	9535
·01	12743	·51	12066	·01	11407	·51	10763	·01	10136	·51	9523
·02	12729	52	12053	·02	11394	·52	10751	·02	10124	·52	9511
·03	12715	·53	12039	·03	11381	·53	10738	·03	10111	·53	9499
·04	12701	·54	12026	·04	11368	·54	10725	·04	10099	·54	9487
19 05	12688	19·55	12013	20·05	11355	20·55	10713	21·05	10087	21 55	9475
·06	12674	·56	11999	·06	11342	·56	10700	·06	10074	·56	9463
·07	12661	·57	11986	·07	11329	·57	10688	·07	10062	·57	9451
·08	12647	·58	11973	·08	11316	·58	10675	·08	10049	·58	9439
·09	12633	·59	11960	·09	11303	·59	10662	·09	10037	·59	9427
19·10	12620	19·60	11946	20·10	11290	20·60	10649	21·10	10025	21·60	9415
·11	12606	·61	11933	·11	11277	·61	10637	·11	10012	·61	9403
·12	12592	·62	11920	·12	11264	·62	10624	·12	10000	·62	9390
·13	12579	·63	11906	·13	11251	·63	10612	·13	9988	·63	9378
·14	12565	·64	11893	·14	11238	·64	10599	·14	9976	·64	9366
19·15	12551	19·65	11880	20·15	11225	20·65	10586	21·15	9963	21·65	9354
·16	12538	·66	11867	·16	11212	·66	10573	·16	9950	·66	9342
·17	12524	·67	11854	·17	11199	·67	10561	·17	9938	·67	9330
·18	12511	·68	11840	·18	11186	·68	10549	·18	9926	·68	9318
·19	12497	·69	11827	·19	11173	·69	10536	·19	9914	·69	9306
19·20	12484	19·70	11813	20·20	11160	20·70	10523	21·20	9901	21·70	9294
·21	12470	·71	11800	·21	11147	·71	10511	·21	9889	·71	9282
·22	12457	·72	11787	·22	11135	·72	10498	·22	9877	·72	9270
·23	12443	·73	11774	·23	11122	·73	10486	·23	9865	·73	9258
·24	12429	·74	11760	·24	11109	·74	10473	·24	9853	·74	9246
19·25	12416	19·75	11747	20·25	11096	20·75	10460	21·25	9840	21·75	9234
·26	12402	·76	11734	·26	11083	·76	10448	·26	9828	·76	9222
·27	12389	·77	11721	·27	11070	·77	10435	·27	9815	·77	9210
·28	12375	·78	11708	·28	11057	·78	10423	·28	9803	·78	9198
·29	12362	·79	11694	·29	11045	·79	10411	·29	9791	·79	9186
19·30	12348	19·80	11681	20·30	11032	20·80	10398	21·30	9779	21·80	9174
·31	12335	·81	11669	·31	11019	·81	10385	31	9767	·81	9162
·32	12321	·82	11656	·32	11006	·82	10373	·32	9754	·82	9151
·33	12308	·83	11642	·33	10993	·83	10360	·33	9742	·83	9139
·34	12294	·84	11629	·34	10981	·84	10348	·34	9730	84	9127
19 35	12281	19·85	11616	20·35	10968	20·85	10335	21·35	9718	21·85	9115
·36	12267	·86	11603	·36	10955	·86	10323	·36	9706	·86	9103
·37	12254	·87	11590	·37	10942	·87	10310	·37	9694	·87	9091
·38	12241	·88	11577	·38	10929	·88	10298	·38	9681	·88	9079
·39	12227	·89	11564	·39	10916	·89	10285	·39	9669	·89	9067
19·40	12214	19·90	11551	20·40	10904	20·90	10273	21·40	9657	21·90	9055
·41	12200	·91	11538	·41	10891	·91	10261	·41	9644	·91	9043
·42	12187	·92	11524	·42	10878	·92	10248	·42	9632	·92	9031
·43	12173	·93	11511	·43	10865	·93	10235	·43	9620	·93	9019
·44	12160	·94	11498	·44	10853	·94	10223	·44	9608	·94	9007
19·45	12146	19·95	11485	20·45	10840	20·95	10211	21·45	9596	21·95	8996
·46	12133	·96	11473	·46	10827	·96	10198	·46	9584	·96	8984
·47	12119	·97	11459	·47	10814	·97	10186	·47	9572	·97	8972
·48	12106	·98	11446	·48	10802	·98	10173	·48	9560	·98	8960
·49	12093	·99	11433	·49	10789	·99	10161	·49	9547	·99	8948

In. dec.	Feet.	In. dec	Feet.	In. dec.	Feet.	In. dec	Feet.	In. dec.	Feet.	In. dec.	Feet.
22·00	8936	22·50	8351	23·00	7778	23·50	7217	24·00	6669	24·50	6131
·01	8924	·51	8339	·01	7766	·51	7206	·01	6658	·51	6121
·02	8912	·52	8327	·02	7755	·52	7195	·02	6647	·52	6110
·03	8901	·53	8316	·03	7744	·53	7184	·03	6637	·53	6100
·04	8889	·54	8305	04	7733	·54	7173	·04	6626	·54	6089
22·05	8877	22·55	8293	23·05	7721	23·55	7162	24·05	6615	24·55	6079
·06	8865	·56	8281	·06	7710	·56	7151	·06	6604	·56	6068
·07	8854	·57	8270	·07	7699	·57	7140	·07	6593	·57	6057
·08	8842	·58	8258	·08	7687	·58	7129	·08	6582	·58	6047
·09	8830	·59	8246	·09	7676	·59	7118	·09	6571	·59	6036
22·10	8818	22·60	8235	23·10	7665	23·60	7107	24·10	6560	24·60	6025
·11	8806	·61	8224	·11	7654	·61	7096	·11	6550	·61	6015
·12	8794	·62	8212	·12	7642	·62	7085	·12	6539	·62	6004
·13	8783	·63	8201	·13	7631	·63	7074	·13	6528	·63	5994
·14	8771	·64	8189	·14	7620	·64	7063	·14	6517	·64	5983
22·15	8759	22·65	8177	23·15	7609	23·65	7052	24·15	6506	24·65	5972
·16	8747	·66	8166	·16	7597	·66	7041	·16	6496	·66	5962
·17	8735	·67	8155	·17	7586	·67	7030	·17	6485	·67	5951
·18	8724	·68	8143	·18	7575	·68	7019	·18	6474	·68	5941
·19	8712	·69	8132	·19	7564	·69	7008	·19	6463	·69	5930
22·20	8701	22·70	8120	23·20	7552	23·70	6997	24·20	6452	24·70	5920
·21	8689	·71	8108	·21	7541	·71	6986	·21	6442	·71	5910
·22	8677	·72	8097	·22	7530	·72	6975	·22	6431	·72	5899
·23	8665	·73	8086	·23	7519	·73	6964	·23	6421	·73	5888
·24	8654	·74	8074	·24	7507	·74	6953	·24	6410	·74	5878
22·25	8642	22·75	8063	23·25	7496	23·75	6942	24·25	6399	24·75	5867
·26	8630	·76	8051	·26	7485	·76	6931	·26	6388	·76	5857
·27	8618	·77	8040	·27	7474	·77	6920	·27	6377	·77	5846
·28	8606	·78	8029	·28	7463	·78	6909	·28	6367	·78	5836
·29	8595	·79	8017	·29	7451	·79	6898	·29	6356	·79	5825
22·30	8584	22·80	8006	23·30	7440	23·80	6887	24·30	6345	24·80	5815
·31	8572	·81	7994	·31	7429	·81	6876	·31	6335	·81	5804
·32	8560	·82	7982	·32	7418	·82	6865	·32	6324	·82	5794
·33	8548	·83	7971	·33	7407	·83	6854	·33	6313	·83	5783
·34	8537	·84	7960	·34	7396	·84	6843	·34	6302	·84	5773
22·35	8525	22·85	7948	23·35	7384	23·85	6832	24·35	6292	24·85	5762
·36	8513	·86	7937	·36	7373	·86	6821	·36	6281	·86	5752
·37	8501	·87	7925	·37	7362	·87	6811	·37	6270	·87	5741
·38	8490	·88	7914	·38	7351	·88	6800	·38	6260	·88	5731
·39	8479	·89	7903	·39	7340	·89	6788	·39	6249	·89	5720
22·40	8467	22·90	7891	23·40	7328	23·90	6777	24·40	6238	24·90	5710
·41	8455	·91	7880	·41	7317	·91	6767	·41	6227	·91	5699
·42	8443	·92	7869	·42	7306	·92	6756	·42	6217	·92	5689
·43	8432	·93	7858	·43	7295	·93	6745	·43	6206	·93	5678
·44	8420	·94	7846	·44	7284	·94	6734	·44	6196	·94	5668
22·45	8408	22·95	7835	23·45	7273	23·95	6723	24·45	6185	24·95	5657
·46	8397	·96	7823	·46	7262	·96	6712	·46	6174	·96	5647
·47	8386	·97	7812	·47	7251	·97	6701	·47	6164	·97	5636
·48	8374	·98	7801	·48	7240	·98	6690	·48	6153	·98	5626
·49	8362	·99	7789	·49	7229	·99	6680	·49	6142	·99	5615

In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.
25·00	5605	25·50	5089	26·00	4583	26·50	4087	27·00	3600	27·50	3122
·01	5595	·51	5079	·01	4573	·51	4077	·01	3590	·51	3112
·02	5584	·52	5069	·02	4563	·52	4067	·02	3580	·52	3103
·03	5574	·53	5059	·03	4553	·53	4057	·03	3571	·53	3093
·04	5564	·54	5048	·04	4543	·54	4047	·04	3561	·54	3084
25·05	5553	25·55	5038	26·05	4533	26·55	4038	27·05	3551	27·55	3074
·06	5543	·56	5028	·06	4523	·56	4028	·06	3542	·56	3065
·07	5533	·57	5018	·07	4513	·57	4018	·07	3532	·57	3055
·08	5522	·58	5008	·08	4503	·58	4008	·08	3523	·58	3046
·09	5512	·59	4997	·09	4493	·59	3998	·09	3513	·59	3037
25·10	5501	25·60	4987	26·10	4483	26·60	3989	27·10	3503	27·60	3027
·11	5491	·61	4977	·11	4473	·61	3979	·11	3494	·61	3017
·12	5480	·62	4967	·12	4463	·62	3969	·12	3484	·62	3008
·13	5470	·63	4957	·13	4453	·63	3959	·13	3475	·63	2999
·14	5459	·64	4946	·14	4443	·64	3950	·14	3465	·64	2989
25·15	5449	25·65	4936	26·15	4433	26·65	3940	27·15	3455	27·65	2980
·16	5439	·66	4926	·16	4423	·66	3930	·16	3446	·66	2971
·17	5429	·67	4916	·17	4413	·67	3920	·17	3436	·67	2961
·18	5418	·68	4906	·18	4403	·68	3910	·18	3427	·68	2951
·19	5408	·69	4896	·19	4393	·69	3901	·19	3417	·69	2942
25·20	5398	25·70	4886	26·20	4383	26·70	3891	27·20	3407	27·70	2933
·21	5387	·71	4876	·21	4373	·71	3881	·21	3398	·71	2923
·22	5377	·72	4865	·22	4364	·72	3871	·22	3388	·72	2914
·23	5366	·73	4855	·23	4354	·73	3862	·23	3379	·73	2905
·24	5356	·74	4845	·24	4344	·74	3852	24	3369	·74	2895
25·25	5346	25·75	4835	26·25	4334	26·75	3842	27·25	3359	27·75	2886
·26	5336	·76	4825	·26	4324	·76	3832	·26	3350	·76	2876
·27	5325	·77	4815	·27	4314	·77	3823	·27	3340	·77	2867
·28	5315	·78	4805	·28	4304	·78	3813	·28	3331	·78	2858
·29	5305	·79	4795	·29	4294	·79	3803	·29	3322	·79	2848
25·30	5294	25·80	4784	26·30	4284	26·80	3794	27·30	3312	27·80	2839
·31	5284	·81	4774	·31	4274	·81	3784	·31	3302	·81	2830
·32	5274	·82	4764	·32	4264	·82	3774	·32	3293	·82	2820
·33	5263	·83	4754	·33	4254	·83	3764	·33	3283	·83	2811
·34	5253	·84	4744	·34	4244	·84	3755	·34	3274	·84	2801
25·35	5243	25·85	4734	26·35	4235	26·85	3745	27·35	3264	27·85	2792
·36	5233	·86	4724	·36	4225	·86	3735	·36	3254	·86	2783
·37	5222	·87	4714	·37	4215	·87	3725	·37	3245	·87	2773
·38	5212	·88	4704	·38	4205	·88	3716	·38	3236	·88	2764
·39	5202	·89	4694	·39	4195	·89	3706	·39	3226	·89	2755
25·40	5192	25·90	4684	26·40	4185	26·90	3697	27·40	3217	27·90	2746
·41	5182	·91	4674	·41	4175	·91	3687	·41	3207	·91	2736
·42	5171	·92	4664	·42	4166	·92	3677	·42	3197	·92	2726
·43	5161	·93	4654	·43	4156	·93	3667	·43	3188	·93	2717
·44	5150	·94	4643	·44	4146	·94	3658	·44	3179	·94	2708
25·45	5140	25·95	4633	26·45	4136	26·95	3648	27·45	3169	27·95	2699
·46	5130	·96	4623	·46	4126	·96	3638	·46	3160	·96	2689
·47	5120	·97	4613	·47	4116	·97	3629	·47	3150	·97	2680
·48	5110	·98	4603	·48	4106	·98	3619	·48	3140	·98	2671
·49	5099	·99	4593	·49	4096	·99	3610	·49	3131	·99	2662

In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.	In. dec.	Feet.
28 ·00	2652	28 ·50	2191	29 ·00	1738	29 ·50	1292	30 ·00	854	30 ·50	424
·01	2643	·51	2182	·01	1729	·51	1283	·01	845	·51	415
·02	2633	·52	2173	·02	1720	·52	1274	·02	837	·52	407
·03	2624	·53	2164	·03	1711	·53	1266	·03	828	·53	398
·04	2615	·54	2155	·04	1702	·54	1257	·04	820	·54	389
28 ·05	2605	28 ·55	2145	29 ·05	1693	29 ·55	1248	30 ·05	811	30 ·55	381
·06	2596	·56	2136	·06	1684	·56	1240	·06	802	·56	373
·07	2587	·57	2127	·07	1675	·57	1231	·07	794	·57	364
·08	2578	·58	2118	·08	1666	·58	1222	·08	785	·58	355
·09	2569	·59	2109	·09	1657	·59	1213	·09	776	·59	347
28 ·10	2559	28 ·60	2099	29 ·10	1648	29 ·60	1204	30 ·10	767	30 ·60	338
·11	2550	·61	2090	·11	1639	·61	1195	·11	759	·61	330
·12	2540	·62	2081	·12	1630	·62	1186	·12	751	·62	321
·13	2531	·63	2072	·13	1621	·63	1178	·13	742	·63	313
·14	2522	·64	2063	·14	1612	·64	1169	·14	733	·64	304
28 ·15	2513	28 ·65	2054	29 ·15	1603	29 ·65	1160	30 ·15	724	30 ·65	295
·16	2504	·66	2045	·16	1594	·66	1151	·16	716	·66	287
·17	2494	·67	2036	·17	1585	·67	1142	·17	707	·67	279
·18	2485	·68	2027	·18	1576	·68	1134	·18	698	·68	270
·19	2476	·69	2018	·19	1568	·69	1125	·19	690	·69	262
28 ·20	2467	28 ·70	2009	29 ·20	1559	29 ·70	1116	30 ·20	681	30 ·70	253
·21	2458	·71	2000	·21	1550	·71	1108	·21	673	·71	245
·22	2448	·72	1991	·22	1541	·72	1099	·22	664	·72	236
·23	2439	·73	1981	·23	1532	·73	1090	·23	655	·73	228
·24	2430	·74	1972	·24	1523	·74	1081	·24	647	·74	220
28 ·25	2420	28 ·75	1963	29 ·25	1514	29 ·75	1072	30 ·25	638	30 ·75	211
·26	2411	·76	1954	26	1505	·76	1064	·26	629	·76	202
·27	2402	·77	1945	·27	1496	·77	1055	·27	621	·77	194
·28	2393	·78	1936	·28	1487	·78	1046	·28	612	·78	185
·29	2384	·79	1927	·29	1478	·79	1037	·29	604	·79	177
28 ·30	2374	28 ·80	1918	29 ·30	1469	29 ·80	1028	30 ·30	595	30 ·80	169
·31	2365	·81	1909	·31	1460	·81	1020	·31	586	·81	160
·32	2356	·82	1900	·32	1452	·82	1011	·32	578	·82	152
·33	2347	·83	1891	·33	1443	·83	1003	·33	569	·83	143
·34	2338	·84	1882	·84	1434	·84	994	·84	560	·84	135
28 ·35	2329	28 ·85	1873	29 ·35	1425	29 ·85	985	30 ·35	552	30 ·85	126
·36	2319	·86	1864	·36	1416	·86	976	·36	544	·86	118
·37	2310	·87	1855	·37	1408	·87	967	·37	535	·87	109
·38	2301	·88	1846	·38	1399	·88	959	·38	526	·88	100
·39	2291	·89	1837	·39	1390	·89	950	·39	518	·89	92
28 ·40	2282	28 ·90	1828	29 ·40	1381	29 ·90	941	30 ·40	509	30 90	84
·41	2273	·91	1819	·41	1372	·91	932	·41	500	·91	76
·42	2264	92	1810	·42	1363	·92	924	·42	492	·92	67
·43	2255	·93	1801	·43	1354	. 93	915	·43	484	·93	59
·44	2246	·94	1792	·44	1345	·94	907	·44	475	·94	50
28 ·45	2237	28 ·95	1783	29 ·45	1336	29 95	898	30 ·45	466	30 ·95	42
·46	2228	·96	1774	·46	1328	·96	889	·46	458	·96	34
·47	2218	·97	1765	·47	1319	·97	880	·47	449	·97	25
·48	2209	·98	1756	·48	1310	·98	872	·48	441	·98	17
·49	2200	·99	1747	·49	1301	·99	863	·49	432	·99	8

Approximate Height.	34°	36°	38°	40°	42°	44°	46°	48°
Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
500	2	4	6	8·5	10·5	12·5	14·5	16·5
1,000	4	8	12	17	21	25	29	33
1,500	6	12	18	25·5	31·5	37·5	43·5	49·5
2,000	8	16	24	34	42	50	58	66
2,500	10	20	30	42·5	52·5	62·5	72·5	82·5
3,000	12	24	36	51	63	75	87	99
3,500	14	28	42	59·5	73·5	87·5	101·5	115·5
4,000	16	32	48	68	84	100	116	132
4,500	18	36	54	76·5	94·5	112·5	130·5	148·5
5,000	20	40	60	85	105	125	145	165
5,500	22	44	66	93·5	115·5	137·5	159·5	181·5
6,000	24	48	72	102	126	150	174	198
6,500	26	52	78	110·5	136·5	162·5	188·5	214·5
7,000	28	56	84	119	147	175	203	231
7,500	30	60	90	127·5	157·5	187·5	217·5	247·5
8,000	32	64	96	136	168	200	232	264
8,500	34	68	102	144·5	178·5	212·5	246·5	280·5
9,000	36	72	108	153	189	225	261	297
9,500	38	76	114	161·5	199·5	237·5	275·5	313·5
10,000	40	80	120	170	210	250	292	330
10,500	42	84	126	178·5	220·5	262·5	306·5	346·5
11,000	44	88	132	187	231	275	321	363
11,500	46	92	138	195·5	241·5	287·5	335·5	379·5
12,000	48	96	144	204	252	300	350	396
12,500	50	100	150	212·5	262·5	312·5	3[illegible]4·5	412·5
13,000	52	104	156	221	273	325	379	429
13,500	54	108	162	229·5	283·5	337·5	393·5	445·5
14,000	56	112	168	238	294	350	408	462
14,500	58	116	174	246·5	304·5	362·5	422·5	478·5
15,000	60	120	180	255	315	375	437	495
15,500	62	124	186	263·5	325·5	387·5	451·5	511·5
16,000	64	128	192	272	336	400	466	528
16,500	66	132	198	280·5	346·5	412·5	480·5	544·5
17,000	68	136	204	289	357	425	495	561
17,500	70	140	210	297·5	367·5	437·5	509·5	577·5
18,000	72	144	216	306	378	450	524	594
18,500	74	148	222	314·5	388·5	462·5	538·5	610·5
19,000	76	152	228	323	399	475	553	627
19,500	78	156	234	331·5	409·5	487·5	567·5	643·5
20,000	80	160	240	340	420	500	582	660
21,000	84	168	252	357	441	525	611	693
22,000	88	176	264	374	462	550	640	726
23,000	92	184	276	391	483	575	669	759
24,000	96	192	288	408	504	600	698	792
25,000	100	200	300	425	525	625	727	825
26,000	104	208	312	442	546	650	756	858
27,000	108	216	324	459	567	675	785	891
28,000	112	224	336	476	588	700	814	924
29,000	116	232	348	493	609	725	843	957
30,000	120	240	360	510	630	750	872	990
	30°	28°	26°	24°	22°	20°	18°	16°

Approximate Height.	50°	52°	54°	56°	58°	60°	62°	64°
Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
500	18·5	21	23	25	27	29	31	33
1,000	37	42	46	50	54	58	62	66
1,500	55·5	63	69	75	81	87	93	99
2,000	74	84	92	100	108	116	124	132
2,500	92·5	105	115	125	135	145	155	165
3,000	111	126	138	150	162	174	186	198
3,500	129·5	147	161	175	189	203	217	231
4,000	148	168	184	200	216	232	248	264
4,500	166·5	189	207	225	243	261	279	297
5,000	185	210	230	250	270	290	310	330
5,500	203·5	231	253	275	297	319	341	363
6,000	222	252	276	300	324	348	372	396
6,500	240·5	273	299	325	351	377	403	429
7,000	259	294	322	350	378	406	434	462
7,500	277·5	315	345	375	405	435	465	495
8,000	296	336	368	400	432	464	496	528
8,500	314·5	357	391	425	459	493	527	561
9,000	333	378	414	450	486	522	558	594
9,500	351·5	399	437	475	513	551	589	627
10,000	370	420	460	500	540	580	620	660
10,500	388·5	441	483	525	567	609	651	693
11,000	407	462	506	550	594	638	682	726
11,500	425·5	483	529	575	621	667	713	759
12,000	444	504	552	600	648	696	744	792
12,500	462·5	525	575	625	675	725	775	825
13,000	481	546	598	650	702	754	806	858
13,500	499·5	567	621	675	729	783	837	891
14,000	518	588	644	700	756	812	868	924
14,500	536·5	609	667	725	783	841	899	957
15,000	555	630	690	750	810	870	930	990
15,500	573·5	651	713	775	837	899	961	1023
16,000	592	672	736	800	864	928	992	1056
16,500	610·5	693	759	825	891	957	1023	1089
17,000	629	714	782	850	918	986	1054	1122
17,500	647·5	735	805	875	945	1015	1085	1155
18,000	666	756	828	900	972	1044	1096	1188
18,500	684·5	777	851	925	999	1073	1127	1221
19,000	703	798	874	950	1026	1102	1158	1254
19,500	721·5	819	897	975	1053	1131	1189	1287
20,000	740	840	920	1000	1080	1160	1220	1320
21,000	777	882	966	1050	1134	1218	1282	1386
22,000	814	924	1012	1100	1188	1276	1344	1452
23,000	851	966	1058	1150	1242	1334	1406	1518
24,000	888	1008	1104	1200	1296	1392	1468	1584
25,000	925	1050	1150	1250	1350	1450	1530	1650
26,000	962	1092	1196	1300	1404	1508	1592	1716
27,000	999	1134	1242	1350	1458	1566	1654	1782
28,000	1036	1176	1288	1400	1512	1624	1716	1848
29,000	1073	1218	1334	1450	1566	1682	1778	1914
30,000	1110	1260	1380	1500	1620	1740	1840	1980
	14°	12°	10°	8°	6°	4°	2°	0°

Centimetres	Metres.	Centimetres	Metres.	Centimetres	Metres.	Centimetres	Metres.	Centimetres	Metres.	Centimetres	Metres.
25·5	8966	30·5	7540	35·5	6330	40·5	5280	45·5	4356	50·5	3528
·6	8935	·6	7515	·6	6307	·6	5260	·6	4339	·6	3512
·7	8904	·7	7489	·7	6285	·7	5241	·7	4321	·7	3496
·8	8873	·8	7462	·8	6262	·8	5222	·8	4304	·8	3480
·9	8842	·9	7436	·9	6239	·9	5202	·9	4286	·9	3464
26·0	8811	31·0	7410	36·0	6217	41·0	5183	46·0	4269	51·0	3449
·1	8780	·1	7385	·1	6195	·1	5164	·1	4252	·1	3433
·2	8750	·2	7360	·2	6173	·2	5145	·2	4235	·2	3418
·3	8720	·3	7334	·3	6151	·3	5126	·3	4218	·3	3402
·4	8689	·4	7309	·4	6129	·4	5107	·4	4201	·4	3386
26·5	8659	31·5	7283	36·5	6107	41·5	5086	46·5	4183	51·5	3371
·6	8629	·6	7258	·6	6086	·6	5066	·6	4166	·6	3356
·7	8598	·7	7233	·7	6064	·7	5047	·7	4149	·7	3341
·8	8568	·8	7207	·8	6042	·8	5028	·8	4132	·8	3325
·9	8538	·9	7182	·9	6020	·9	5009	·9	4115	·9	3310
27·0	8508	32·0	7157	37·0	5999	42·0	4991	47·0	4097	52·0	3295
·1	8479	·1	7132	·1	5977	·1	4972	·1	4080	·1	3279
·2	8450	·2	7108	·2	5956	·2	4953	·2	4064	·2	3264
·3	8421	·3	7084	·3	5935	·3	4934	·3	4047	·3	3249
·4	8392	·4	7059	·4	5914	·4	4915	·4	4031	·4	3234
27·5	8363	32·5	7034	37·5	5892	42·5	4896	47·5	4014	52·5	3219
·6	8335	·6	7009	·6	5871	·6	4878	·6	3998	·6	3203
·7	8306	·7	6985	·7	5850	·7	4859	·7	3981	·7	3188
·8	8277	·8	6961	·8	5829	·8	4840	·8	3965	·8	3173
·9	8248	·9	6936	·9	5807	·9	4822	·9	3948	·9	3158
28·0	8220	33·0	6912	38·0	5786	43·0	4804	48·0	3931	53·0	3143
·1	8191	·1	6888	·1	5765	·1	4786	·1	3914	·1	3128
·2	8163	·2	6864	·2	5744	·2	4768	·2	3898	·2	3113
·3	8135	·3	6840	·3	5723	·3	4750	·3	3882	·3	3098
·4	8107	·4	6816	·4	5703	·4	4732	·4	3865	·4	3083
28·5	8079	33·5	6793	38·5	5682	43·5	4713	48·5	3849	53·5	3069
·6	8052	·6	6769	·6	5662	·6	4695	·6	3832	·6	3054
·7	8024	·7	6745	·7	5641	·7	4677	·7	3816	·7	3039
·8	7997	·8	6721	·8	5621	·8	4659	·8	3799	·8	3024
·9	7969	·9	6697	·9	5600	·9	4641	·9	3783	·9	3009
29·0	7942	34·0	6674	39·0	5580	44·0	4622	49·0	3767	54·0	2995
·1	7915	·1	6651	·1	5559	·1	4604	·1	3751	·1	2980
·2	7888	·2	6628	·2	5538	·2	4586	·2	3735	·2	2966
·3	7861	·3	6605	·3	5518	·3	4568	·3	3719	·3	2951
·4	7834	·4	6582	·4	5498	·4	4550	·4	3703	·4	2937
29·5	7807	34·5	6559	39·5	5479	44·5	4533	49·5	3686	54·5	2922
·6	7780	·6	6536	·6	5459	·6	4515	·6	3670	·6	2908
·7	7753	·7	6513	·7	5439	·7	4497	·7	3654	·7	2893
·8	7726	·8	6490	·8	5419	·8	4479	·8	3638	·8	2879
·9	7699	·9	6467	·9	5399	·9	4461	·9	3622	·9	2864
30·0	7673	35·0	6444	40·0	5379	45·0	4444	50·0	3607	55·0	2849
·1	7646	·1	6421	·1	5359	·1	4426	·1	3591	·1	2834
·2	7620	·2	6398	·2	5339	·2	4409	·2	3575	·2	2820
·3	7594	·3	6376	·3	5319	·3	4391	·3	3560	·3	2806
·4	7568	·4	6353	·4	5299	·4	4374	·4	3544	·4	2792